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Control of Infiltration and Inflow into Sewer Systems

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27 Abstract
~~A study was made of~~ problems were studied of infiltration of ground and surface waters into sanitary sewers and inflows from various connections to these sewers. ~~The "infiltration" water is surface or ground~~ Such water ~~that~~ enters sewers through joints, cracks, breaks or indirectly through perforated or loose manhole covers or other faulty sewer structures. "Inflows" water is piped into the sewer from basement and foundation drains, roof leaders, and other legal or illegal connections of storm sewers and combined sewers. Two hundred and twelve public jurisdictions in the United States and Canada were contacted, and twenty-six communities were visited. Practices of consulting engineers and state and provincial water pollution control agencies were also surveyed. The surveys indicated that infiltration and inflow are widespread problems. Reduction of infiltration should be stressed in both new and old systems. For new sewers a construction allowance of no more that 200 gallons per day per inch of diameter per mile of pipe is recommended. Existing systems must be extensively investigated to determine the extent and location of infiltration. Reduction of inflow waters can be accomplished after sources of such flows have been identified, alternate methods of disposal identified, and the backing of public and governing bodies secured. Twenty recommendations are given indicating the need for extensive investigation of the extent of the infiltration/inflow problem before relief sewers are constructed or wastewater treatment plants built or enlarged. (~~Poertner~~) (WRSIC abstract)

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CONTROL OF INFILTRATION AND INFLOW INTO SEWER SYSTEMS

by the

AMERICAN PUBLIC WORKS ASSOCIATION

for the

ENVIRONMENTAL PROTECTION AGENCY
WATER QUALITY OFFICE

and

THIRTY-NINE LOCAL GOVERNMENTAL JURISDICTIONS

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ABSTRACT

Two hundred and twelve public jurisdictions in the United States and Canada were contacted, and twenty-six communities were visited. Practices of consulting engineers and state and provincial water pollution control agencies were also surveyed.

The surveys indicated that infiltration and inflow are widespread problems.

Reduction of infiltration should be stressed in both new and old systems. For new sewers a construction allowance of no more than 200 gallons per day per inch of diameter per mile of pipe is recommended. Existing systems must be extensively investigated to determine the extent and location of infiltration. Reduction of inflow waters can be accomplished after sources of such flows have been identified, alternate methods of disposal identified, and the backing of public and governing bodies secured.

Twenty recommendations are given indicating the need for extensive investigation of the extent of the infiltration/inflow problem before relief sewers are constructed or wastewater treatment plants built or enlarged.

The report includes 43 tables, an extensive review of reports concerning local infiltration studies, and a bibliography of 135 references.

This report was prepared for the Environmental Protection Agency in fulfillment of Contract 14-12-550. The study was also supported by thirty-nine public agencies. A companion document, "Manual of Practice, Prevention and Correction of Excessive Infiltration and Inflow into Sewer Systems," was also prepared.

Key Words: INFILTRATION, INFLOW, INVESTIGATION, INSPECTION, SURVEY.

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SECTION 1

FINDINGS AND RECOMMENDATIONS OF THE STUDY

What are the causes, effects, and means of correcting excessive extraneous waters entering public sewer systems as a result of infiltration and inflow? These investigations, surveys, and research activities were designed to provide dependable information on which to base practical guidelines for eliminating or minimizing these conditions. The national study project carried out by the American Public Works Association on behalf of the Water Quality Office of the Environmental Protection Agency and 38 participating jurisdictional agencies has demonstrated the importance of this problem and defined workable ways for coming to grips with it.

Outlined here are the study's most significant findings on this problem and its impact on sewer systems, urban areas, sewage pumping and treatment facilities, combined sewer overflows, and national water resources quality. On the basis of these findings, recommendations for action are offered local jurisdictions, state and provincial regulatory agencies, the consulting engineering profession, sewer construction contractors, and manufacturers and service companies serving this field.

This report deals with two sources of extraneous waters which enter the sewer system: infiltration which is ground water, and inflows which are the result of pipe connections. A full definition of both items is given in Section 2.

Findings and recommendations of the study are as follows:

1. Infiltration of ground water is an important source of large volumes of waste water flow in sanitary and combined sewer systems – in all areas in jurisdictions of all sizes, with all types of sewer pipe construction and various types of jointing materials, and regardless of the type of soil formations in which the sewers are laid. Infiltration may average as much as 15 percent of the total flows handled by affected sewer systems; peak infiltration rates may be 30 percent. Under unusual conditions a separate sanitary sewer system may assume the flow characteristics of a combined sewer. In spite of the adverse effect of infiltration, the importance of this problem has not been universally recognized.

The most important sources of infiltration include defective sewer pipe, defective joints, and defective manholes. Inflow waters, as differentiated from infiltration, have sources in other parts of urban areas and sewer systems.

Greater recognition of this problem's importance on the part of sewer system administrators, sewer designers, pollution control agencies, contractors and manufacturers, must be achieved before widescale corrective actions can be considered and consummated. All sources of infiltration should be held suspect before great volumes of extraneous waters can be eliminated or minimized realistically.

2. Infiltration is affected by ground water levels. A large percentage of public sewers, now representing a national total length of 2,942 million feet of sewer pipe of various sizes and a national monetary outlay of over $50 billion, are laid at depths which expose them to ground water infiltration during wet or dry weather conditions. These conditions should influence construction of watertight sewers.

Construction of sewers must be carried out in dry trench conditions by means of adequate pumping or well-point control of water levels. Conduits must be laid and joints prepared under proper pipe bedding conditions. Proper backfilling and compaction of trench material must be practiced as the best safeguard against adverse ground water conditions in all affected construction projects.

3. Sewer system officials and designers have available a wide choice of sewer pipe materials, in various sizes, strengths and lengths. The national survey disclosed the diversity of choices of such sewer pipe types to meet specific preferences and serve specific purposes.

Sewer pipe should be chosen not only on the basis of design strength and construction criteria, but with full recognition of the relationship between types of sewer pipe and infiltration control.

4. Great improvements have been made in pipe jointing materials and installation practices. The use of flexible compression gaskets for forming joints has increased at a high rate for all types of sewer pipe and manhole structures. Designers, sewer system administrators, and contractors reported that this type of joint has improved sewer-laying practices and greatly reduced infiltration through joints, the greatest point of entry of infiltration water into sewer systems.

No sewer pipe or manhole is better than its joints. The choice of joints should be made with full recognition of their importance in infiltration control, and they should be installed in conformity with the recommendations of manufacturers. The

best joint will not be watertight if installed carelessly or improperly.

5. In spite of the great improvements in pipe and joint materials and in construction methods, excessive infiltration construction allowances are specified by many designers, sewer system officials, and water pollution control agencies. There is some tendency to reduce such allowances and require relatively "tight" sewer construction. Present infiltration allowances vary widely and are expressed in varying units of performance; the predominating requirement is approximately 500 gallons per inch of sewer diameter per mile of pipe. However, reductions in this allowance are beginning to appear in design and construction practice.

The capabilities of modern pipe and joint materials should be recognized in setting infiltration allowances; more rigid and lower infiltration allowances of 200 gallons per day per inch diameter per mile of sewer should be required wherever structurally possible and economically feasible. Designers should adopt rational infiltration criteria rather than following standards proposed by other authorities under conditions that can be overcome by modern methods and materials. Designers must make a clearer distinction between infiltration allowances in sewer design and infiltration allowances in sewer construction, in planning modern sewers to meet today's urban growth problems.

6. Infiltration seriously affects the operation of sewer systems and pumping, treatment, and overflow regulator facilities. It also adversely affects the urban environment and the quality of water resources. The effects include: usurpation of sewer capacities that should be reserved for present sanitary sewage flows and future urban growth; need for construction of relief sewer facilities prior to originally scheduled dates; surcharging and backflooding of sewers into public roads and streets and private properties; by-passing of raw sewage at various points of spill or diversion into storm sewers or nearby watercourses; surcharging of pumping stations, with resultant excessive wear on equipment, higher power costs or by-passing of flows to adjacent water sources; surcharging of waste water treatment plants, with adverse consequences to treatment efficiencies, diversion of flow from secondary-tertiary treatment stages, or by-passing of volumes of untreated waste water into receiving waters; increases in the incidence and duration of storm water overflows at combined sewer regulator stations.

The effect of these conditions on urban sanitation and water pollution should be recognized when considering correction of infiltration. Any overall decisions on infiltration control policies should recognize the inconsistency of large expenditures for advanced waste water treatment facilities to handle excessive infiltration flows.

7. Exfiltration from defective sewer pipe, joints and other adjunctive parts of sewer systems often is a significant aspect of the operation and maintenance of sewer systems. Exfiltration can be the cause of ground water pollution and, like infiltration, can undermine sewer lines and produce pipe failures and pavement cave-ins.

Sources of exfiltration should be located whenever sewage flows in downstream sections of sewer systems indicate an unexplained loss of flow volumes. A policy that such losses of flow are "good riddance" must be avoided; exfiltration points should be corrected.

8. The installation of low rate infiltration sewer lines can be assured by enforcement of rigid construction infiltration specifications, backed up by alert and unremitting inspection of construction, and followed up by effective sewer inspection and testing procedures prior to acceptance. Sewer inspection and testing methods have been improved markedly. The use of closed-circuit television techniques, photographic methods, smoke test and air test procedures, and other practices offer sewer officials and designers the opportunity to "see the unseen" and locate points of infiltration in new and existing sewer systems.

The capabilities of new inspection-testing methods should be recognized and used whenever applicable. The expense of such methods in many instances will be outweighed by the benefits derived. Research should be undertaken to provide practical correlations between test results such as those provided by air and exfiltration tests and actual infiltration rates, to gain compliance with more restrictive infiltration allowances.

Rigid inspection should be provided on all construction projects, since prevention of infiltration is cheaper and more effective than correction after installation.

9. Methods for the sealing of defective sewer pipe and joints, by physical and chemical means, are widely used to correct infiltration conditions in existing sewer systems. Internal and external application methods are available. Sewer sections or joints actually are replaced in cases requiring physical reconstruction to allay the effects of excessive infiltration.

The new methods of sealing points of excessive

infiltration should be known and evaluated before any decisions are made on major rehabilitation procedures. Before such work is instituted it will be necessary to carry out sewer inspection operations by the modern methods referred to above. Such surveillance methods should be preceded by sewer-line cleaning to make meaningful the investigation of the sources and extent of infiltration. A step-by-step multi-phase cleaning-inspection-testing correction program is the only way to assure effective rehabilitation of existing sewers. Experienced sewer service organizations are available in all parts of the country to carry out this type of overall program or assist in portions of such multi-phased projects.

10. Building sewers play an important role in infiltration and contribute to the problems caused by this type of excessive extraneous water. In some cases the infiltration volumes from building sewers are equal to, or greater than, the amount of infiltration resulting from defective pipe and joints in street sewers. The total length of building sewers in built-up urban areas may exceed the footage of street sewers into which they discharge.

Greater attention should be given to requiring correction of building sewer defects to reduce infiltration in existing sewer systems. Sewer agency officials should make surveys of building sewer conditions as a part of any overall system survey of infiltration sources.

11. Improved control over installation of new building sewers, including effective specifications covering type of pipe, joints, rigid inspection, and approval procedures, can reduce infiltration from this source. Many jurisdictions experience divided authority and responsibility for installation and connection of building sewers – with plumbing or housing officials controlling the section of such sewers between the building and the property line, and sewer, public works, or engineering agencies maintaining authority over the section between the property line and the street sewer.

Divided authority over building sewers can void proper control over this important source of infiltration. Wherever feasible, a single authority should be provided, or coordinated actions by separate agencies should be encouraged. Jurisdictions should provide for more definitive specifications for building sewer construction, more complete inspection of lines before they are backfilled, and programs of testing to assure watertightness. Street sewer stubs awaiting building construction and connections, as well as abandoned building sewer connections, should be tightly sealed to eliminate infiltration through open lines.

12. State and provincial water pollution control agencies recognize infiltration as an important factor in sewer system and sewage pumping, treatment and disposal capabilities, and water pollution control. However these groups frequently maintain less than adequate control over infiltration rate allowances and local adherence to such standards of practice. The pressures of other phases of waste water collection and treatment, coupled with inadequate staff personnel, reportedly limit the attention given to infiltration control.

State and provincial agencies should give greater attention to infiltration control, because of the effect these excessive incursions into sewer systems have on the effective life span of these systems, by-passing of sewer lines, pumping installations, waste water treatment processes, and consequent pollution control in receiving waters.

13. The benefits derived from the elimination of, and the cost of, excessive infiltration can be determined by rational mathematical analyses. Findings can be used to ascertain the costs versus benefits balance and justification of proposed corrective procedures.

Jurisdictions, wherever possible, should carry out definitive analyses of the effects and costs of infiltration and the costs of corrective measures. Sound fiscal decisions should be based on overall long range costs and other factors such as water quality impairment due to such infiltration.

Federal and state agencies should grant funds for complete infiltration surveys and necessary corrective actions, as a way to reduce the size and costs of waste water handling and treatment facilities to be financed with participating federal and state funds.

14. The inflow of extraneous waters into sewer systems can seriously reduce the carrying capacities of sewers; cause local flooding and inundation of private property; produce surcharging of sewage pumping stations and waste water treatment works; impair treatment efficiencies; induce excessive and over-long overflows from combined sewer systems, and create local water pollution conditions.

Officials of sewer agencies should be increasingly aware of the effects of inflow into sewer systems. Sewer-use ordinances or other types of codes or regulations should be invoked and strictly enforced to relieve the deleterious effects of excessive inflow.

15. The major sources of inflow into public sewers include: roof leaders, manhole covers, cellar and foundation drains, and entry and yard drains. Many such connections exist in contravention of local

regulations. Others result from failure of jurisdictions to impose regulations or enforce them when in effect. In many cases the volumes of inflow waters far exceed the quantities anticipated when certain inflow connections were authorized. Removal of inflow sources may entail a heavy cost to the homeowner and a great deal of inconvenience.

Where no control over inflows is in effect, jurisdictions should consider enacting necessary regulations. Where sewer-use regulations are in effect they should be firmly enforced. Where inflows are permitted under present regulations, jurisdictions should evaluate the effects of these inflows and take action to discontinue them if this is deemed necessary to protect the serviceability of sewer systems and appurtenant waste water facilities. Illicit and surreptitious inflow connections should be eliminated by a system of search and surveillance.

The success of such corrective actions will depend on public cooperation plus full participation and support from elective officials who represent property owners. Efforts should be launched to inform and educate the public on the importance of control of inflow. Public educational aids such as motion pictures depicting the value of sewers in the life and progress of urban areas, and the importance of inflow and infiltration control, should be developed. These could help win public support for the normally unpopular task of getting property owners or local jurisdictions to invest funds for eliminating inflow connections.

16. The discharge of so-called "clean waters" from such sources as commercial air conditioning, industrial process cooling, and other points of excessive inflow into sanitary and combined sewers seriously affects these systems and waste water handling facilities.

Jurisdictions should encourage commercial and industrial water users to practice on-stream reclamation and reuse of such "clean waters," thereby reducing the hazards of inflows and curtailing excessive use of public water supplies.

17. Many jurisdictions report that manhole covers are used to drain flooded areas into sanitary and combined sewers, thus overloading these systems to the peak. In other areas, storm water accumulates over, and flows into, manholes.

Permanent solutions to drainage problems should be sought. Adequate separate storm water drainage should be provided. If manholes are located in vulnerable areas, perforated covers should be replaced with tight covers to reduce entry of storm water into sewer lines.

18. Surcharged sanitary sewers often are relieved by sewer maintenance crews who interconnect these lines with nearby storm sewers or surface watercourses, without the full knowledge or consent of administrators or sewer design agencies. Such a break in communications between those who plan and design sewer systems and those who operate them exists in many jurisdictions. A similar lack of communication exists between jurisdictions discharging into multi-community sewer systems and the agency receiving and treating these flows. In these instances, the communities served have little inducement to eliminate infiltration and inflows, other than the need to prevent local flooding.

Sewer agencies should discourage maintenance crews from using diversion procedures in emergency relief of surcharged sewers, until and unless proper authorization is given and the interconnections recorded on maps in the design engineering office. Communication should be encouraged between central waste water interception and treatment agencies and communities served. In many areas sewer charges are based upon the volume of flow contributed from one jurisdiction to another, minimization of these charges may be the most compelling reason for reduction of infiltration and inflow.

19. The need for more specific knowledge of soil and ground water conditions at sewer construction sites has been stressed by consulting engineering firms and some sewer system officials. Predesign and preconstruction borings of soil and location of ground water tables, frequently are not made a part of the project record.

Soil and ground water conditions should be made a matter of record, to protect both the contractor and the owner against unexpected construction conditions. Better design, tighter infiltration control allowances, and better construction practices will result. The need for claims and counterclaims for construction extras and infiltration noncompliances will be greatly reduced if such preproject information is obtained.

20. As a part of this study, a Manual of Practice was prepared on the means of locating and controlling infiltration and inflow.

Governmental agencies and consulting engineers are urged to consider utilization of the guidelines contained in the Manual of Practice. The information contained in the manual should encourage the ultimate development of "Standards of Practice," wherever such criteria are feasible and desirable.

SECTION 2

INFILTRATION AND INFLOW PROBLEMS: AN OVERVIEW

Infiltration of ground water and inflow of extraneous waters of all types into United States and Canadian sewer systems are problems of growing concern. They have an adverse effect on economic and environmental conditions in local sewers and contiguous land areas, and on pumping and treatment facilities; they cause pollution conditions in receiving waters. Both of these extraneous water entries usurp sewer and waste water handling capacities.

The significance of these volumes of extraneous waters which reduce valuable design capacities of urban sanitary, combined, and storm sewer systems was highlighted in the 1967 National Survey entitled "Problems of Combined Sewer Facility Overflows-1967." That survey was carried out by the American Public Works Association for the Federal Water Pollution Control Administration (now the Federal Water Quality Administration).

The report on that previous research project contained this finding:

> "The survey showed that infiltration, during both wet and dry periods, often exceeds design standards and code regulations, usurping needed combined sewer capacities and increasing the frequency and duration of overflows. Reduction in infiltration in existing sewers by means of repairs and reconstruction, and in new sewers by means of better materials, jointing, construction and inspection, offers opportunities to reduce overflows. **It is recommended that in-depth studies for alleviating excessive infiltration and relating it to incidents and durations of overflows be undertaken."**

The effect of infiltration of ground water on combined sewer system overflows and on water pollution adds emphasis to something of even greater importance – usurpation of the capacities of separate sanitary sewer systems intended to carry *all* flows to waste water treatment plant facilities.

The intrusion of extraneous inflow waters into sewer systems from various known and unknown sources, over and above the infiltration flows investigated in the 1967 National Survey, makes it highly important to evaluate the total problem and search for workable corrective actions.

The Federal Water Quality Administration and the American Public Works Association, on behalf of 38 contributing public agencies, entered into a contractual agreement in 1969 to make a national "study of causes and control of ground water infiltration into sewers." This document is a report on this "second generation" research project. The basic purpose of the studies was to investigate the causes, extent, effects, and means of control of the overall extraneous water problems of infiltration and inflow in separate sanitary and combined sewer systems and appurtenant regulator-overflow, pumping and treatment facilities. The requirements of this contract and the way the studies were implemented are described in Section 3 of this report.

The "Two I's"

The contract requirements took cognizance of the two facets of the entry of so-called extraneous waters into sewer systems: infiltration and inflow. The contract defined "Infiltration," in terms of what this report refers to as the "Two I's," in these words:

> "For the purposes of this study, infiltration is defined as the entrance of extraneous flows into sanitary, storm, and combined sewers. In this context the investigations and evaluations will require consideration of extraneous (surface) flows resulting from roof and yard drainage, foundation drains, unpolluted cooling waters and similar flows into the sewers due to cracked or broken pipe, leaky joints, root intrusion, poorly constructed house drains, improper connections to street sewers and similar sources."

Regardless of the sources of waters that enter sewers and affect their ability to provide urban sanitation and drainage, the net result is the same: usurpation or reduction of valuable conduit capacities. The sewer systems so affected cannot distinguish between ground waters which have infiltrated lines through defective points of entry, and those which have flowed into sewers via points of direct pipe connections. However, no investigation of such extraneous waters and their effects on sewer systems can yield meaningful data and practical guidelines for elimination unless the "Two I's" are identified, delineated, and evaluated.

The establishment of a firm definition of the two factors of infiltration and inflow became the first requirement in developing a plan of action for the research project, as described in Section 3. To guide the technical investigators who carried out in-depth, in-the-field surveys of representative systems, and provide practical ground rules for local governmental officials who supplied other statistical survey information, the following definitions were adopted:

> "INFILTRATION" covers the volume of ground water entering sewers and house connections from the soil, through defective joints, broken or cracked pipes, improperly made connections, manhole walls, etc.
>
> "INFLOW" covers the volume of any kinds of water discharged into sewer lines from such sources as roof leaders; cellar and yard area drains; foundation drains; commercial and industrial so-called clean water discharges; drains from springs and swampy areas; etc. It does not include, and is distinguished from, "infiltration" as previously defined.
>
> "INFILTRATION/INFLOW" – This study recognizes that in the case of existing sewer systems it is difficult to distinguish between "infiltration" and "inflow." For this reason, the term "infiltration/inflow" is used to cover those flows of extraneous waters where *totals* of the two types of entry waters are involved.

One clarification of the scope of this study must be made. While the terms of the contract refer to sanitary sewers, combined sewers, and storm sewers, a basic priority had to be established for the investigation. The infiltration and inflow problem is, first and foremost, of major importance in sanitary sewers because they are not designed to handle such extraneous waters in excessive amounts. While infiltration allowances are made in sewer design and construction practice, and certain inflows may be authorized, the ultimate "ideal" of watertight sewers is recognized as the goal of sewer authorities.

In the case of combined sewers, the impact of the "Two I's" is of relatively lesser significance because these dual-purpose conduits are designed to handle drainage and runoff waters similar in nature to infiltration and inflow waters. Problems do arise when the volumes of extraneous waters exceed the handling capacities of sewer lines, overflow facilities, and other system appurtenances.

In the case of storm sewers, the impacts of infiltration and inflow are of even less significance because these conduits are intended to handle the same kind of waste waters represented by the "Two I's."

Infiltration thus is the result of soil conditions, ground water levels, precipitation, interstitial water entrained in overlying soils, materials and methods of construction, and the stability of pipe joints, and manhole and chamber structures and connections. Infiltration is a *physical* factor. The elimination or minimization of such intruded flows involves administrative and financial decisions, along with engineering actions in terms of design, construction, inspection, and corrective procedures.

Inflow is the result of deliberately planned or expediently devised connections of sources of waste water into sewer systems. These connections become the means of disposing of unwanted storm water or other drainage water and liquid wastes into a convenient drain conduit. They can include the deliberate or inadvertent drainage of low areas through manhole covers. Inflow can be the result of authorized discharges, where roof, cellar or foundation drain connections are permitted by local regulation, or where discharges of certian spent waters or wastes into public sewers are authorized. In addition, it can arise from illicit and unknown connections made by property owners or home builders for their convenience and without authorization. The flow from such sources is a result of *operational* conditions that may be located and corrected by regulation and inspection-surveillance procedures, aimed at enforcing regulations relating to sewer connections and use.

Despite these differences in sources and corrective measures, effective control of infiltration and inflow factors have two common denominators: (1) A desire on the part of municipal officials to search out points of entry and take necessary actions to eliminate them, and (2) the willingness of the public to participate in these actions, to the extent of assuming its equitable share of the cost of eliminating illicit connections from its properties, and approving municipal expenditure of funds to correct defective existing sewers and enhance the quality of new construction.

The problem of solving infiltration and inflow may be more difficult in intercommunity or regional sewer systems fostered by today's metropolitan growth trends. A community that is not involved in the interception, pumping, and treatment of its sewage flow, but discharges its wastes into a regional or district system, may have little incentive to eliminate sources of extraneous flows unless charges are based on volume. In some cases treatment charges to each participating municipality based on metered flows are an effective way to stimulate active interest by all parties in reducing points of excessive infiltration and inflow.

The Infiltration Problem

The definitions of infiltration and inflow indicate the sources of these extraneous waste waters. Infiltration effects have been recognized for more than a half-century but only current developments, in terms of urban growth and increased concern over water pollution conditions, have focused attention on the problem. Sewer construction materials and methods have been greatly improved by these stimuli. The important research and development work carried out by manufacturers of pipe, joint, and appurtenant sewer system facilities has recently produced significant technical advances in this field. The upsurge of federal and state demands for higher levels of sewage treatment to prevent pollution and protect the environment makes excessive infiltration and inflow critical. Corrective actions now are essential.

Prior to the present stepped-up clean waters efforts at national and state levels, the effects of extraneous flows from both sources were of less importance. In a sanitary engineering sense, the gradual usurpation of sewer system capacity was of less significance then because the slow urban growth of the past precluded sudden demands on design capacities assigned to future growth in population and water consumption. Local sewer surcharging and backflooding were not as frequent as they are today. When only a portion of the nation's sewage flows was treated or inadequately treated, environmental control authorities were less concerned with the pollutional effects of excessive combined sewer overflows and by-passing of sewage from separate sanitary sewers and treatment plants into receiving waters.

This era of minor seriousness is gone, as demonstrated by the consummation of this infiltration-inflow survey contract with federal and local funds. All levels of government recognize the importance of the problem outlined in the findings of the 1967 National Survey. Proof of the changed attitude towards correction of infiltration conditions is found in recent FWQA-sponsored research studies of workable methods for sealing defective sewer pipe and joints. Still further proof is the upsurge in measures now being taken by local governments to survey their sewer system infiltration problems and institute corrective measures, such as replacement of defective sewer sections; the encasement of defective lines; insertion of tight-sewer tubes within defective lines, and the sealing of leaking sewers by chemical and physical means. It is proper to characterize this shift in infiltration thinking as a trend from medium to maximum concern.

Causes and Sources of Excessive Infiltration

A listing of the major causes of infiltration serves as an indication of the ways infiltration can be reduced:

- Poor or improperly constructed sewer joints.
- Unstable pipe bedding and soil conditions.
- Improper methods of backfilling after sewer construction.
- Open or defective new or abandoned stub connections from building sewers.
- Joints damaged by internal pressure in sewers or improper sewer cleaning or flushing operations.
- Inadequate testing and inspection of sewer construction.
- Improper construction of building sewer lines and their connections into street sewers without adequate control and inspection.
- Improper construction of manholes and other sewer system appurtenances.
- Pipe deterioration from interior or exterior sources.
- Pipe damage at points where conduits are laid in varying soil formations, such as where building sewers cross over from shallow building sewer trenches to deep street trenches.

This research and report have taken cognizance of all of these sources of infiltration, as well as the obvious sources of inflow. They give detailed information on local practices and experiences.

Factors Influencing Control of Infiltration

Repeated emphasis is placed here on infiltration because it is a factor which local governmental action can correct. Inflow is less amenable to control by technical action and engineering practices.

The means of controlling infiltration take two forms: (1) prevention or minimization of infiltration in all future design and construction work; and (2) correction of defects in existing sewer systems. The latter corrections must be based on a survey of existing systems; the location of points of infiltration; the determination of the amounts of infiltration involved and the physical causes, and the correction of these infiltration defects if cost-versus-benefit analyses show it to be warranted. Corrective measures involve "healing" and "sealing" of the points of entry by means of materials and techniques now available.

Corrections, in some cases, may be effected only by complete or partial replacement or reconstruction of defective sewer sections or appurtenant structures.

Minimization of all future infiltration rates will require the application of engineering principles of design, the use of effective pipe and joint materials, proper construction and jointing methods, and the inspection, testing, and acceptance of sewer lines which meet rigidly drawn and tightly enforced standards.

The Inflow Problem

Inflow connections that usurp sewer capacities pose a challenging demand for better administrative regulation and enforcement practices.

Crystallization of interest in inflow sources and their control has not been as strongly evident as it is in the case of infiltration. While infiltration rate criteria have been established as an approach to engineering design standards, the amount of inflow necessarily has been indeterminate and undetermined. The physical connections that contribute large volumes of liquid flows have been less subject to engineering determination and technological corrections. This excessive flow increment, to a great extent, has been influenced by human and political factors. It is an anomaly that the urban population and housing explosion, and burgeoning industrial-commercial growth, may be adversely affected by inflow into sanitary sewer's from residential buildings and business structures. The service life expectancy of sanitary sewers may be shortened by flows which normally require no treatment and which more properly could be diverted to urban storm drainage lines or recycled for reuse in industrial and commercial operations.

New local administrative policies may foretell greater control of inflow conditions. The adoption of sewer-use regulations or ordinances is being encouraged by technical organizations, and municipal acceptance of this important policy is becoming more prevalent. However, public support is the most vital ingredient. This embraces willingness on the part of builders and realty developers to restrict the introduction of roof, foundation, and basement drainage into house connections to public sewers; willingness of property owners to search out and correct illicit connections, and a desire of property owners to cooperate with municipal regulations aimed at eliminating or reducing such inflows. From their monetary obligations for such corrective action, property owners will get dividends not always immediately evident to them, such as reduction of surcharging of sewers and elimination of local backflooding into their property and onto adjacent lands.

Effects of Infiltration and Inflow

Little attention has been given in the past to determining the amount of infiltration and inflow carried by existing sewer systems. Part of this lack must be attributed to an inability to differentiate between infiltration and inflow when excessive flows are experienced in existing sewer systems. The problem has been confused further by the inability to attribute seriously increased flows in sewer systems, pumping stations, and treatment plants to the direct inflow of storm water flows or to infiltration – or to deliberate or unavoidable interconnections of sewer lines by the governmental jurisdictions themselves. Marked increases in separate sanitary sewer flows are commonly experienced during storm periods. These conditions have produced the following effects on sewer networks and appurtenant portions of these systems.

- Flooding of local sections of sewers and inundation of streets and roads.
- Backflooding into private properties.
- Increased cost of pumping.
- Reduced life of pumping station equipment (because of excessive operation).
- Increased cost of sewage treatment plant operation.
- Reduced life of sewage treatment plant equipment and devices (because of excessive loading and longer periods of operation).
- Clogging of sewers with sand and soils which are waterborne by infiltration flows.
- Clogging of sewers with root growths which find their way into conduits via the same points of entry available to infiltration water.
- Reduction in the ability of existing sewers to accommodate new urban developments.
- Need for new sewer construction to replace the capacities pirated by infiltration and inflow.
- Street and road failures due to undermining of surface areas by infiltration and sand and soil intrusion into sewer systems.
- Inadequate treatment of sewage flows, due to overtaxing of process capacities with infiltration and inflow volumes.
- By-passing of flows from separate sanitary sewers at pumping stations to alleviate surcharges in pits, pumps, and force mains.

- By-passing of excessive peak flows from sanitary sewers into storm drains or local streams to prevent or reduce local back-up and flooding of streets and private properties.
- Diversion of parts of flows from sewage treatment plant processes, and inadequate treatment during excessive periods of infiltration and inflow.
- Spills of excessive amounts of combined sewer flows at regulator-overflow structures.

The presence of infiltration even during dry-weather periods indicates the problem that contributes to combined sewer overflows during periods of storm runoff.

Exfiltration, the leakage from sewers into the surrounding soil, can pollute ground water, endanger the quality of well supplies, and cause subsurface washouts that can produce instability of sewer structures and ultimate failure.

Most of these factors have an important and direct impact on pollution conditions of the receiving waters. Present efforts to achieve higher standards of effluent quality by means of advanced degrees of treatment, and funds dedicated to maintaining more rigid quality standards in public waters, will be thwarted or rendered financially unsound if infiltration and inflows are permitted to rob sewers of carrying capacities and treatment plants of their process performance capabilities.

The Ideal Sewer System

Correction of the most important sources of infiltration is physically possible and, in many cases, economically feasible. Modern day methods of underground surveys can locate sewer system defects. In a majority of cases, sewer stability can be restored without excavating pavement and interfering with the flow of urban traffic and the public convenience. Again, in this phase of corrective action, new sealant techniques now are available and are being improved by chemical formulations and application methods.

New sewer construction also can meet the criteria of practical idealism. Improved types of sewer pipe are available, and new jointing practices can assure watertight construction and almost complete freedom from infiltration without sacrificing the desired flexibility of sewer conduits. Better methods of trench preparation and sewer laying can assure construction under dry conditions that will provide proper alignment of sewer pipes, full soil support, and clean joints. New methods of testing for sewer leaks can be used to guarantee compliance with more rigid infiltration limits. The trend in infiltration allowances is on the "down" side. Former specification allowances of 500 gallons per mile per inch of diameter of pipe, or more, have been revised to 200 or 100 gallons or less. The engineering profession is beginning to recognize that bottletight sewers are not an idealistic impossibility.

The "ideal" sewer system, in brief, is one which minimizes infiltration and limits inflow points to prevent usurpation of capacities; is free from stoppages due to root growth; has effective self-scouring capacities, and delivers to pumping and sewage treatment facilities the flows that need purification in order to prevent pollution of receiving waters.

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SECTION 3

CONTRACT PROVISIONS AND IMPLEMENTATION

The goal of this research study was to produce reliable information on the causes, extent, and control of storm and ground water infiltration into sanitary and combined sewers – data that would be useful to designers and contractors, and to planning, operating, maintenance and inspection forces of urban-area public agencies having responsibilities for sanitary and combined sewers.

Contract Provisions

The contract covering this project stipulated: "The contractor shall investigate and determine the current state of the art relating to the technical, economic and social aspects of infiltration of extraneous waters into sanitary, storm, or combined sewers. The extent, causes and corrective measures relating to infiltration shall be reported and evaluated with specific needs for research and development efforts identified."

To clarify the two types of extraneous water flows covered by the research project, the staff developed specific terminology for distinguishing one from the other. The clarification of these basic terms is outlined in Section 2 of this report. Infiltration refers to the classic concept of extraneous water entering the sewer system through broken pipes, faulty joints, or other defects in the system. Inflow consists of other extraneous waters connected directly by pipes or drains to the sanitary sewer or combined sewer system from such sources as those enumerated in the contract document. The concept of inflow also embraces storm waters entering sewer lines through manhole covers. Infiltration is a measure of the physical condition of the system while inflow reflects the extent of use or misuse of the system in permitting, legally or illegally, the actual connection of pipes carrying surface, ground, roof, and in-structure discharges.

Project Staff Organization

To conduct the survey effectively and utilize valid national information to produce the required report and manual, the following staff personnel and advisory groups were appointed:

- A project directer was selected from the permanent American Public Works Association staff in Chicago to assume overall responsibility for planning the program of action and for direction and major decisions as the project progressed.
- A principal investigator was designated and a regional field office was set up at Yardley, Pennsylvania, where most of the project operations and data collection were centered. He was a full time APWA Research Foundation employee, exclusively assigned to this project.
- A staff consultant, with broad experience in sanitary engineering and municipal sewer system practices, and in the preparation and editing of research reports, was designated to participate in all phases of the project.
- An Advisory Committee was formed, representing all municipal jurisdictions that were supporting the project by direct contribution of funds. Each participating jurisdiction assigned a member of their agency to the Advisory Committee. The committee was apprised of all pertinent study plans and kept informed of the progress of the project through monthly reports. The members were called upon to provide specific project-survey data based on their professional experience and intimate knowledge of all facets of infiltration and inflow problems.
- A Steering Committee of six members was created. Four of these members were selected from the Advisory Committee while the American Society of Civil Engineers and the Water Pollution Control Federation each were invited to designate one member. The Steering Committee met at various intervals during the planning and performance of the project to review investigative programs and evaluate study findings, and guide the staff in interpreting survey data.
- A Consulting Engineers' Panel was selected to work with the staff. Three firms, one each from the east, west, and central areas of the United States, were chosen to provide technical advice on the planning and execution of the project; participate in the interviews needed for the national in-the-field investigation of representative jurisdictions, and prepare technical material for the report and manual.
- An Industrial Advisory Panel was created, on the basis of volunteer action, to represent manufacturers, contractors, and sewer service

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organizations in the fields involved in sewer infiltration problems and their correction. The panel chose to assign its work to three subcommittees which devoted specific attention to sewer pipe and joint materials; sewer construction practices, and sewer maintenance, infiltration surveys and corrective actions.

- A small group of engineering investigators was selected to supplement the staff and consulting engineers panel in conducting in-the-field studies and evaluations of sewer infiltration problems and practices in the 26 representative jurisdictions chosen for the national investigation. These investigators were selected for their experience in the field and their intimate knowledge of sewer construction and operating procedures in specific areas of the United States and Canada.
- Special consultants and staff assistants were selected to provide additional technical data in the following categories: (1) Literature search in the general field of sewer infiltration and inflow; (2) economic evaluation of the effects and correction of infiltration and inflow; (3) soil mechanics and hydrology, as they relate to infiltration control; (4) review of ordinances relating to sewer use and waste water discharge into sewer systems, and (5) collation of survey data to expedite their interpretation and evaluation.

Implementation of Contract

The contract stipulated that the project would be conducted in three phases, as follows:

Phase I – Literature Search

A literature search was instituted to provide technical reference material of value to officials of jurisdictions, consulting engineers, and regulatory agencies, as well as assist the project staff. A bibliography of selected articles, reports and other manuscripts pertaining to infiltration and inflow of extraneous waters was prepared. A staff assistant collated technical data from the libraries of the Joint Engineering Societies, New York City; Columbia University; Princeton University, and many other colleges and institutions. The editorial offices of technical magazines and official organization journal offices were visited for a review of their files. In addition to a list of pertinent literature in this field, copies of important reference material were obtained for staff use. Although a large number of references were researched, many were repetitious and others were deemed to have only secondary or tertiary significance to the project problems. It became evident that despite the importance of the infiltration-inflow problem, there was no great wealth of technical material on many important facets of the subject. The most pertinent literature references usually related to specific case histories and system crises. The finalized version of the bibliography is contained in Section 11 of this report.

Phase II – Detailed Goals

Phase II, as delineated in the contract, listed 15 specific areas for investigation and interpretation. To produce the data required, the following surveys and investigations were initiated:

(1) State and Provincial Water Pollution Control Regulatory Agency Survey

Fifty states and eight Canadian provinces were surveyed to ascertain their practices and policies relating to infiltration and inflow control. The response to this inquiry was 100 percent in both nations. The specific purposes for the survey were to:

- Determine state regulatory practices.
- Ascertain state activity in setting infiltration design factors.
- Determine the opinion of state officials on the extent and importance of infiltration.
- Obtain a supplemental list of jurisdictions which, in the opinion of the regulatory agencies, had significant infiltration problems or had solved such problems by unusually effective practices.

(2) Field Investigation of Infiltration and Inflow Problems

Twenty-six local jurisdictions in the United States and Canada were selected for in-depth in-the-field investigations of infiltration and inflow problems and solutions. The choice of these jurisdictions was based on information obtained from previous research projects on sewer system and water pollution conditions. The investigations were designed to provide definitive information on sewer system design, construction, operation and maintenance practices, and on corrections of infiltration and inflow problems. *Representative* information rather than *statistical* data was sought. The findings, as reported by trained professional evaluators, have been the basis of a great deal of the information contained in the body of this report. The major purposes of these specific investigations were to:

- Delineate causes of infiltration and inflow conditions.
- Determine the effects of infiltration and inflow on the entire sewer system.
- Disclose design and construction standards used by these jurisdictions.
- Ascertain the testing and inspection methods used in sewer construction and maintenance.
- Explore local policies relating to sewer system materials and methods.
- Determine the methods used for detecting and correcting infiltration and inflow.
- Explore economic evaluations, methods, and cost data relating to infiltration effects and corrective measures.
- Determine methods for controlling sewer inflow through sewer-use regulations.

(3) National Statistical Survey

A survey was conducted on infiltration and inflow conditions in municipalities and jurisdictions throughout the United States and Canada, selected on a scheduled statistical basis. Jurisdictions initially were selected for each state and province on the following basis:

- All cities above 200,000 population.
- Half the cities of 100,000 to 199,999.
- One-fifth of all cities of 20,000 to 99,999.
- Two or three cities of 10,000 to 19,999.
- One city below 10,000.

When the survey data were received, they were collated and interpreted on a regional basis, as follows:

East: Connecticut, Delaware, Indiana, Kentucky, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia, District of Columbia

South: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee.

Midwest: Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Wisconsin.

Southwest: Arizona, New Mexico, Oklahoma, Texas.

West: Alaska, California, Colorado, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming.

The inquiry to Canadian jurisdictions was made and evaluated on the basis of population only.

Because of the statistical manner in which the surveyed jurisdictions were selected, the authors of this report assume that the data which the project developed are representative of overall practices and conditions. The evaluation and interpretative discussion of various phases of the national survey, as contained in sections of this report, are based on this assumption.

Table 1, National Statistical Survey – Jurisdictions Responding, indicates the size range and geographical distribution of jurisdictions responding.

The general purposes of the survey were:

- To determine the nationwide extent of infiltration problems on a statistical basis.
- To delineate the causes of infiltration.
- To determine the effects of infiltartion and inflow on sewer systems, pumping stations, sewage treatment works, combined sewer regulator-overflow facilities, and other appurtenant system facilities.
- To ascertain the design and construction standards and requirements.
- To evaluate the testing and inspection methods used in sewer construction and maintenance.
- To determine local practices and standards covering sewer system pipe nformation and joint materials.
- To determine the methods used for infiltration and inflow correction and control.
- To gather economic data on the effects and cost of infiltration correction.
- To determine methods used to control inflow and regulate sewer-use

(4) Consulting Engineering Survey

The project surveyed practices of national consulting engineering firms to obtain cross-sectional information covering their knowledge and experience in sewer system design, construction and maintenance as it related to control of infiltration and inflow. One hundred and seventy consulting engineering firms were contacted; 66 supplied information. The main purposes of this survey were to:

- Determine design factors for infiltration.
- Obtain information on typical design specifications and construction practices.
- Evaluate professional opinions on performance characteristics of sewer-system materials.
- Evaluate opinions on sources and effects of infiltration.

TABLE 1
NATIONAL STATISTICAL SURVEY–JURISDICTIONS RESPONDING

Population	200,000	100,000– 199,999	20,000– 99,999	10,000– 19,999	Under 10,000	Totals
A. United States						
East	9	7	23	5	1	45
South	8	6	10	4	0	28
Midwest	4	6	16	7	2	35
Southwest	7	2	10	4	2	25
West	7	8	30	11	3	59
Subtotal	35	29	89	31	8	192
No. in U. S.	61	69	750	1,041	16,434	
% of U.S. Cities Rep. in Survey	57	42	12	3		
B. Canada	4	2	10	3	2	21
Total	39	31	99	34	10	213

- Collect information on methods of infiltration detection and correction.
- Determine the experiences of consultants in eliminating illegal sewer connections and other sources of inflow.

(5) Building Sewer Connection Survey

A special survey was carried out to determine infiltration-inflow control policies and building sewer-connection experience in the jurisdictions that participated in the project financing.

To achieve this purpose, opinions were solicited from system officials who were members of the project Advisory Committee.

Phase III – Report and Manual

As stated in the contract, the principal objective of Phase III of the project was the preparation of a "Manual of Recommended Practice" and a report on the findings of the study. The Manual, published as a separate document, covers the three general areas enumerated in Phase II, namely:

(1) Design and Construction
(2) Maintenance
(3) Regulatory Practices

The subsequent sections of this report constitute a record of the findings and evaluation of the surveys and investigations carried out as parts of this project. They formed the basis for the findings and recommendations presented in this report.

SECTION 4

THE INFILTRATION PROBLEM: CAUSES, EFFECTS, PREVENTION AND CURE

Excessive infiltration is a serious problem in the design, construction, operation, and maintenance of sewer systems. Neither combined sewers nor separate sanitary sewers are designed to accept large quantities of such infiltration flows.

The problem of infiltration involves two basic areas of concern: (1) Prevention in new sewers by adequate design, construction, inspection, and testing practices, and (2) the elimination or cure of existing infiltration in old sewers by proper survey, investigation, and corrective measures.

Control of infiltration in new sewer systems involves engineering decisions and specification of the methods and materials of sewer construction; pipe, joints, and laying procedures and techniques. Specifications must be prepared with an awareness of the nature of service required of sewer lines, including the presence of any deleterious sewage or waste flows which could diminish the integrity or life of the sewer structure after it has been placed in service.

Control of sewer infiltration in new construction becomes a challenge to provide sewers that can do the job, and then protect them against any damaging conditions by means of sewer-use ordinances or regulations. Specifications must provide for trench and soil control that will assure a firm and safe foundation for sewer lines. They must recognize that variable stability of soils on an integral section of sewer can impose stresses and strains that will make the best-built lines with the highest quality pipe and joints subject to shifting and breakage or the opening of joints.

Effective control of infiltration, therefore, depends on a two-yronged approach to the problem:

1. **Prevention** of infiltration is an engineering-construction problem. The methods involve proper predesign investigation and consideration of soil conditions, ground water levels and seasonal variations, anticipated wastewater flows, capacities of existing sewers, pumping stations and treatment facilities, and all other factors which may influence infiltration rates and the effects of such extraneous waters on the serviceability and operability of the entire system. Weighing these factors, decision is then to be made on choice of pipe and joints, methods of construction, and on inspection, testing and acceptance practices.

2. **Cure** of infiltration involves doing something about the sewer pipe already in the ground and in service. Elimination or minimization of infiltration must be based on survey and investigation of existing sewers and appurtenant structures in order to locate sources of infiltration; determination of the extent of infiltration and the need for correction or sealing of leaks; choice of methods to be used, and proper application of the curative method chosen.

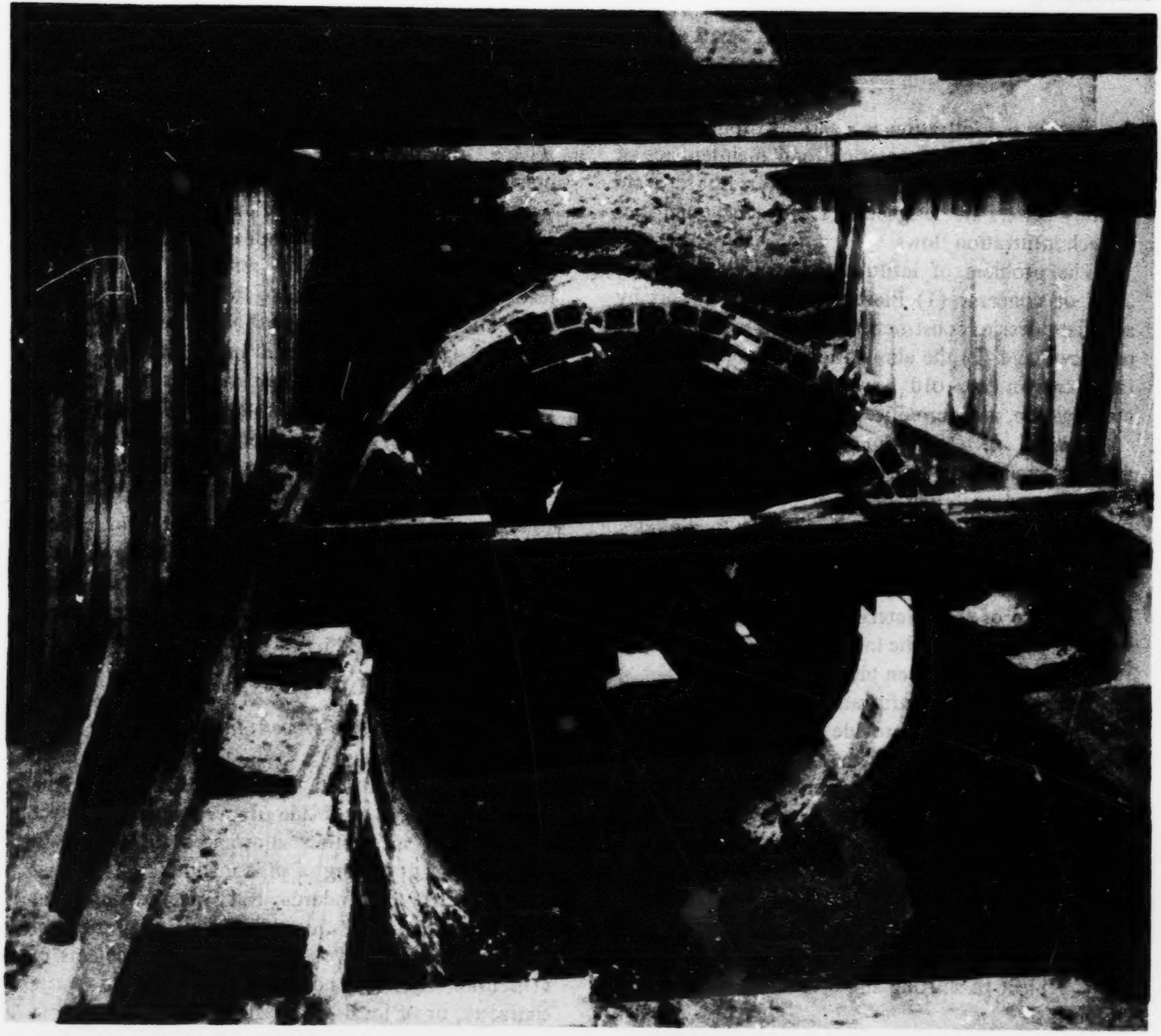
The types of pipe and joints used in sewer construction have an important bearing on the prevention and cure of infiltration. The effectiveness of installation and the conditions under which they function can have an equally great influence on the tightness of ultimate sewer structures and their ability to resist excessive ground water entry while in service. Figure 1, Vitrified Clay Segmental Block Sewer, is a photograph of a large sewer installed in Akron Ohio in 1930. Here, as in brick sewers, the extreme amount of mortar joints often has lead to high infiltration rates.

Types of Sewer Pipe to Prevent Infiltration in New Construction

Improvements in pipe material assure the designer's ability to provide proper materials to meet any rational infiltration allowances he wishes to specify. The upgrading of pipe manufacture to meet rigid quality standards and specifications has eliminated the basic question of watertightness of pipe material. However, there may be problems of structural rigidity and strength of waste water character, or of local soil or gradient conditions that would make one material better suited than another – or preferable under certain special installation conditions. In such cases or situations, pipe materials are chosen for reasons other than their relative resistance to infiltration. During the conduct of the project surveys it was found that many consulting engineers and municipal engineers base their choice of sewer pipe on such special considerations.

In sections of the country where low ground water levels and light precipitation prevail, infiltration itself is not a problem and therefore is seldom considered in setting sewer design standards. Nevertheless, a pipe that fails because of inadequate strength or resistance to subsurface pressures will crack and thereby permit infiltration or exfiltration,

FIGURE 1



Courtesy: United States Concrete Pipe Co.

VITRIFIED CLAY SEGMENTAL BLOCK SEWER AKRON, OHIO (1937)

depending on the location of the sewer in relation to ground water. A pipe conduit system that is structurally sound when constructed and retains its soundness in service will be less prone to abnormal infiltration. However, in today's practice the material or element of the sewer system that most influences infiltration rates is the joint rather than the pipe itself.

Choice of Sewer Pipe

During the course of the study many representative jurisdictions and consulting engineering firms were asked to list the types of sewer pipes which they specify, wwth particular emphasis on control of infiltration.

A large number of engineers reported that almost all pipe materials and modern joints are capable of producing infiltration-free sewers. In many instances, therefore, the design engineers indicated that the sewer pipe materials were selected on the basis of strength or corrosion resistance characteristics rather than for infiltration control.

TABLE 2
NATIONAL FIELD INVESTIGATIONS SEWER PIPE MATERIALS AND JOINTS IN SERVICE

Agency	Pipe in Service	% of Total System	Typical Joints in Service [1]
Baltimore, Md.	Cast Iron	5%	Mortar, "O" Ring, Mechanical
	Concrete (Monolithic)	15%	No Joints
	Reinforced Concrete	5%	Mortar, "O" Ring
	Vitrified Clay	75%	Cement, "O" Ring
Bloomington, Minn.	Cast Iron	3%	"O" Ring
	Reinforced Concrete	15%	Mortar, "O" Ring
	Vitrified Clay	80%	Asphaltic, "O" Ring
	Plastic (Truss)	1%	Chemical Weld
	Other	1%	–
Dallas, Texas	Asbestos Cement	0.82%	"O" Ring
	Brick	0.82%	Mortar
	Cast Iron	0.82%	Lead
	Concrete	37.40%	Mortar, Plastic
	Reinforced Concrete	3.70%	Mortar, Plastic
	Truss	0.82%	Chemical Weld
	Vitrified Clay	55.54%	"O" Ring
	Bit. Coated Corr. Metal	0.08%	
Denver, Colorado	Cast Iron	–	Mechanical
	Concrete	–	Asphalt, "O" Ring, Mortar
	Vitrified Clay	–	Poured, Mortar, ASTM 425
	Reinforced Concrete	–	Asphalt, "O" Ring, Mortar
District of Columbia, Wash.	Reinforced Concrete	10%	"O" Ring
	Vitrified Clay	90%	"O" Ring, Bituminous
Ft. Lauderdale, Florida	Cast Iron	5%	Gasket, Poured Lead
	Concrete	7%	Mortar
	Vitrified Clay	88%	GK, ASTM C-425
Hot Springs, Ark	Concrete	40%	Mortar, "O" Ring, Hot Asphalt
	Vitrified Clay	60%	Mortar, Hot Pour, ASTM C-425
	Cast Iron	<1%	Lead, "O" Ring
Indianapolis, Ind.	Cast Iron	–	Mechanical "O" Ring
	Concrete	–	Mortar
	Reinforced Concrete	–	"Tylox", "O" Ring
	Vitrified Clay	–	ASTM C-425, Unilock, Amvit, Wedgelock

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[1] Description is that given by respondents. Thus, both cement and mortar were given. Several names for compression gaskets such as "O" Ring, Plastic, ASTM C-425, Unilock, Amvit, Wedgelock, Tylox, Neoprene, and Plastisol were given.

TABLE 2 (Continued)

Agency	Pipe in Service	Total System	Typical Joints in Service
Richmond, Va.	Concrete	–	Mortar, "O" Ring
	Reinforced Concrete	–	Mortar, "O" Ring
	Vitrified Clay	–	–
	Brick	–	–
San Jose, Calif.	Asbestos Cement	.5%	"O" Ring
	Concrete	.5%	"O" Ring
	Reinforced Concrete	10%	"O" Ring
	Vitrified Clay	89%	Mortar, "Plastisol"
Savannah, Ga.	Asbestos Cement	–	"O" Ring
	Concrete	–	Mortar, "O" Ring
	Reinforced Concrete	–	"O" Ring, Mortar
	Vitrified Clay	–	Mortar, ASTM C-425
	Truss	–	Chemical Weld
Suburban Sanitary Comm., Washington, D. C. (2)	Asbestos Cement	0.10%	"O" Ring
	Concrete	77.9%	Mortar, "O" Ring
	Reinforced Concrete	1%	Mortar, "O" Ring
	Vitrified Clay	5%	"O" Ring, Mortar
Toronto, Canada	Asbestos Cement	–	–
	Reinforced Concrete	–	–
	Vitrified Clay	85%	–
Watsonville, Calif.	Concrete	5%	Mortar
	Reinforced Concrete	10%	Steel Sleeve, "O" Ring
	Vitrified Clay	85%	Plastisol
Winnipeg, Canada	Asbestos Cement	15%	"O" Ring
	Cast Iron	5%	Mechanical
	Concrete	37.5%	Mortar, Neoprene Gasket
	Reinforced Concrete	37.5%	Mortar, Neoprene Gasket
	Steel	<1%	Welded River Crossing
	Brick	5%	Mortar
Yakima, Washington	Asbestos Cement	.5%	"O" Ring
	Cast Iron	.5%	Lead
	Concrete	74%	Mortar, "O" Ring
	Reinforced Concrete	15%	"O" Ring
	Vitrified Clay	10%	Mortar, Asphalt, "O" Ring

(2) Agency owns and operates trunk sewers only

TABLE 2 (Continued)

Agency	Pipe in Service	Total System	Typical Joints in Service
Jacksonville, Fla.	Asbestos Cement	1%	"O" Ring
	Cast Iron	2%	Mechanical, "O" Ring, Poured
	Reinforced Concrete	26%	"O" Ring, Epoxy/Asbestos
	Vitrified Clay	70%	GK, ASTM 425
	Truss	1%	Chemcial Weld
Janesville, Wisc.	Cast Iron	<1%	Lead, Mechanical
	Concrete	25%	"O" Ring, Mortar
	Plastic (Truss)	<1%	Mortar, Weld
	Reinforced Concrete	25%	"O" Ring, Mortar
	Vitrified Clay	50%	Hot Asphalt, Amvit
Knoxville, Tenn.	Concrete	–	Mortar, "O" Ring
	Reinforced Concrete	–	Mortar, "O" Ring
	Vitrified Clay	–	Mortar, ASTM C-425
New Orleans, La.	Asbestos Cement	–	"O" Ring
	Cast Iron	–	Lead, Gasket
	Concrete	–	Mortar
	Plastic	–	Chemical Weld
	Vitrified Clay	–	Poured, ASTM C-425
Princeton, N.J.	Asbestos Cement	25%	"O" Ring
	Vitrified Clay	75%	"O" Ring, Bituminous, Mortar
Milwaukee, Wisc.	Concrete	80%	Mortar, Asphalt, PVC, "O" Ring
	Vitrified Clay	20%	Mortar, Asphalt, Neoprene
Nassau County, N.Y. (2)	Asbestos Cement	7%	"O" Ring
	Reinforced Concrete	93%	"O" Ring
Oakland County, Michigan	Asbestos Cement	<1%	"O" Ring
	Cast Iron	<1%	Hot Poured, Mechanical
	Concrete	36%	"O" Ring, Asphaltic
	Plastic	<1%	Chemical Weld
	Reinforced Concrete	22%	"O" Ring, Asphaltic
	Steel	<1%	Mechanical
	Vitrified Clay	42%	ASTM C-425
Omaha, Nebraska	Cast Iron	<1%	Lead, Mechanical
	Concrete (Plain & Rein.)	27%	Mortar, Asphaltic
	Plastic	<1%	Chemical Weld
	Steel	<1%	Welded, Mechanical
	Vitrified Clay	73%	Mortar, Asphalt, Prefab.
New Providence, N. J.	Asbestos Cement	80%	"O" Ring
	Cast Iron	1%	Lead
	Vitrified Clay	19%	"O" Ring, Mortar

Table 2, National Field Investigations – Sewer Pipe Materials and Joints in Service, presents data on the various types of pipes in service in the 26 representative jurisdictions investigated.

In the field investigation of 26 representative jurisdictions, all indicated that they used some vitrified clay and concrete pipe in sewer construction. Vitrified clay generally is used in sizes up to 24 inches in diameter; reinforced concrete is more often specified for 24-inch pipe and larger. Twelve of the jurisdictions reported the use of asbestos-cement pipe; in one case, this pipe constituted 95 percent of the collection system in the small sizes. Eight jurisdictions had tried plastic pipe to a limited extent. Cast iron was used for special construction purposes, such as stream crossings and areas close to wells, and when extreme structural strength was required.

Sixty-six consulting engineering firms throughout the United States and Canada provided information on the types of pipe materials they specify in their practices. Table 3, Consulting Engineers Survey – Summary of Pipe Materials Specified, lists the data obtained in this survey. In sizes under 18 inches, asbestos-cement and vitrified clay are very close to equal in frequency of designer specification. Twenty firms reported that vitrified clay was most frequently chosen, and 17 firms listed asbestos-cement as the most frequently chosen. The frequent use of cast iron pipe, the third most often cited material, indicated the number of problem areas requiring extra-strength materials.

Consultants were asked to stipulate the type of pipe specified in "second-frequency" position in their design practices. Use of vitrified clay as a second choice was reported by 17 firms, cast iron by 15, and asbestos-cement by 14.

The responses to a similar inquiry from more than 200 jurisdictions throughout the United States and Canada revealed a similar proportion using various pipe materials. The results are shown in Table 4, National Statistical Survey – Sewer Pipe Material In Use, and are classified in terms of sections of the United States and Canada and population sizes of the respondent jurisdictions.

The responses indicated that for sanitary sewers vitrified clay pipe has been used by 166 jurisdictions in 212 existing systems; concrete pipe by 94 jurisdictions; reinforced concrete in 91; cast iron in 81, and asbestos cement in 42. This trend was consistent in all regions, but jurisdictions in the Southwest, South, and Midwest reported very little past use of asbestos-cement while the East and West indicated greater use of asbestos-cement.

TABLE 3
CONSULTING ENGINEERS SURVEY SUMMARY OF PIPE MATERIALS SPECIFIED TO REDUCE INFILTRATION

Number of Firms Reporting by Type of Pipe Specified

	A. Under 18" in Diameter						
Pipe Material	Order of Choice						
	1	2	3	4	5	6	7
Asbestos Cement	17	14	6	3	1	2	2
Cast Iron	13	15	5	4	1	1	
Concrete	4	5	5	9	4	5	4
Plastic	6	2	8	2	3	4	4
Reinforced Concrete	2	6	12	7	8	2	1
Steel	1	1	1	6	6	3	3
Vitrified Clay	20	17	13	6	4	1	2
	B. Over 18" in Diameter						
Asbestos Cement	7	8	6	1	1	2	1
Cast Iron	8	10	7	2	1		
Concrete	6	3	3	3	1	3	3
Plastic	1	1	2		1	3	4
Reinforced Concrete	32	14	3	3	2		
Steel	2	2	3	7	4	1	
Vitrified Clay	6	13	8	2	2	2	1

The same jurisdictions were asked to report the pipe materials now being specified, in the hope of determining any clear-cut changes in design practices. Table 5, National Statistical Survey – Sewer Pipe Material Specified, summarizes replies.

The total findings for sanitary sewers paralleled those reported in Table 4: Vitrified clay was reported as currently used in 154 jurisdictions; reinforced concrete in 97; cast iron in 71; concrete in 62, and asbestos-cement in 47. Thus there was a slight increase in the percentage specifying asbestos-cement and a small decrease in vitrified clay. It must be emphasized that these figures are for total systems, since certain pipe materials may have greater uses in jurisdictions with special soil or water problems. Furthermore, it must not be assumed that these selections of pipe materials are based solely on infiltration control criteria.

Sewer Jointing to Control Infiltration

The effectiveness of sewer joints for the control of infiltration is so important that – axiomatically speaking – no sewer system is better than its joints. A good joint must be watertight, root penetration-tight, resistant to the effects of soil and sewage, longlasting, and flexible.

TABLE 4

NATIONAL STATISTICAL SURVEY
SEWER PIPE MATERIAL IN USE
Number of Agencies Reporting Type of Sewer Material in Use by Type of Sewer System

Region	Population Groups	Number[1] in Group	Separate Sanitary								Separate Storm								Combined Sewers							
			Asbestos Cement	Brick	Cast Iron	Concrete	Plastic	Reinf. Concrete	Truss	Vitrified Clay	Asbestos Cement	Brick	Cast Iron	Concrete	Plastic	Rein. Concrete	Truss	Vitrified Clay	Asbestos Cement	Brick	Cast Iron	Concrete	Plastic	Rein. Concrete	Truss	Vitrified Clay
East	200,000+	9	0	2	0	0	0	2	0	4	0	2	0	2	0	3	0	4	0	5	0	3	0	6	0	5
	100,000-199,999	7	3	2	4	4	0	3	0	6	0	1	1	2	0	5	0	4	0	3	0	1	0	2	0	4
	20,000- 99,999	23	5	6	7	10	1	11	2	19	0	5	2	11	1	13	0	15	2	5	2	3	0	6	1	8
	10,000- 19,999	5	2	0	1	2	1	3	1	4	0	0	0	2	0	4	0	2	0	0	1	4	0	5	0	4
	Under 10,000	1	0	0	1	0	0	0	0	1	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0
Sub-Total		45	11	10	13	16	2	19	3	34	0	9	4	18	1	25	0	26	2	13	3	11	0	19	1	23
South	200,000+	8	0	0	3	5	0	3	0	5	0	2	1	2	0	5	0	3	0	1	0	1	0	1	0	0
	100,000-199,999	6	0	0	1	3	0	3	0	2	1	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0
	20,000- 99,999	10	0	0	5	5	0	6	0	10	0	2	0	5	2	4	0	2	0	0	0	0	0	0	0	0
	10,000- 19,999	4	0	0	1	2	0	0	0	4	0	0	0	4	1	1	0	0	0	0	0	0	0	0	0	0
	Under 10,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-Total		28	0	0	10	15	0	12	0	21	1	4	2	12	3	11	0	6	0	1	0	1	0	1	0	0
Midwest	200,000+	4	0	1	2	1	0	3	0	3	0	1	1	2	1	3	0	3	0	3	1	2	0	3	0	3
	100,000-199,999	6	1	2	2	2	0	5	0	5	0	3	0	1	1	4	0	5	1	0	0	0	0	0	0	1
	20,000- 99,999	16	5	3	10	9	0	7	1	13	2	4	2	8	1	11	0	8	0	2	0	2	0	2	0	3
	10,000- 19,999	7	0	0	2	2	0	2	0	7	0	0	1	2	0	5	0	3	0	0	0	0	0	1	0	1
	Under 10,000	2	0	0	0	0	0	0	0	2	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0
Sub-Total		35	6	6	16	14	0	17	1	30	2	8	4	15	3	24	0	19	1	6	1	4	0	6	0	6
Southwest	200,000+	7	0	3	4	5	0	6	2	6	0	2	2	4	1	6	0	2	0	0	0	0	0	0	0	0
	100,000-199,999	2	0	0	2	1	0	0	0	2	0	1	0	2	0	2	0	2	0	0	0	0	0	0	0	0
	20,000- 99,999	10	3	0	4	5	0	4	0	8	0	0	0	4	0	6	0	0	0	0	0	0	0	0	0	0
	10,000- 19,999	4	0	0	3	0	0	0	3	0	0	0	1	0	0	2	0	1	0	0	0	0	0	0	0	0
	Under 10,000	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-Total		25	3	3	13	11	0	10	5	18	0	3	3	10	1	16	0	5	0	0	0	0	0	0	0	0
West	200,000+	7	2	2	4	5	1	6	0	6	0	3	0	4	1	4	0	3	0	3	3	2	0	2	0	4
	100,000-199,999	8	2	1	7	3	1	7	0	8	1	1	1	7	1	7	0	4	0	0	3	3	0	2	0	3
	20,000- 99,999	30	12	1	14	15	0	10	0	28	2	1	3	12	1	15	0	3	0	0	0	1	0	1	0	1
	10,000- 19,999	11	2	0	0	8	1	2	0	7	0	0	1	4	1	2	0	0	1	0	0	1	0	0	0	2
	Under 10,000	3	0	0	1	1	1	1	0	2	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0
Sub-Total		59	18	4	26	32	4	26	0	51	3	5	5	28	5	29	0	11	1	3	6	7	0	5	0	10
Canada	200,000+	4	0	0	0	1	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	1
	100,000-199,999	2	1	0	0	1	0	2	0	1	0	0	0	1	0	2	0	1	0	1	0	1	0	1	0	0
	20,000- 99,999	10	2	0	1	2	0	3	0	4	0	0	1	6	0	6	0	3	0	1	0	3	0	2	0	3
	10,000- 19,999	3	1	0	0	1	0	2	0	2	0	0	0	1	1	3	0	0	0	0	0	1	0	1	0	1
	Under 10,000	2	0	0	1	1	0	0	0	2	0	0	0	1	0	2	0	2	0	0	0	0	0	0	0	0
Sub-Total		21	4	0	2	6	0	7	0	10	0	0	1	10	1	14	0	6	0	2	1	5	1	4	0	5
Total		213	42	23	80	94	6	91	9	164	6	29	19	93	14	119	0	73	4	25	11	28	1	35	1	46

(1) Note: Not all agencies in each group reported data

TABLE 5

NATIONAL STATISTICAL SURVEY
SEWER PIPE MATERIAL SPECIFIED
Number of Agencies Reporting Type of Sewer Pipe Material Specified by Type of Sewer System

			Separate Sanitary								Separate Storm								Combined Sewers							
Region	Population Groups	Number[1] in Group	Asbestos Cement	Brick	Cast Iron	Concrete	Plastic	Rein. Concrete	Truss	Vitrified Clay	Asbestos Cement	Brick	Cast Iron	Concrete	Plastic	Rein. Concrete	Truss	Vitrified Clay	Asbestos Cement	Brick	Cast Iron	Concrete	Plastic	Rein. Concrete	Truss	Vitrified Clay
East	200,000+	9	1	1	2	3	1	6	0	7	1	1	1	5	1	8	0	6	1	1	1	4	1	6	0	6
	100,000-199,999	7	3	0	3	1	0	4	1	7	1	0	1	3	0	6	0	3	1	0	0	0	0	2	0	2
	20,000- 99,999	23	7	0	5	4	1	11	2	15	2	0	1	10	2	18	0	10	2	0	0	3	0	5	0	8
	10,000- 19,999	5	0	0	1	3	0	4	0	3	0	0	2	2	0	5	0	0	0	0	0	1	0	1	0	1
	Under 10,000	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-Total		45	11	1	11	11	2	25	3	32	4	1	5	25	3	37	0	19	4	1	1	8	1	14	0	17
South	200,000+	8	0	0	2	3	0	3	1	3	0	0	2	0	0	5	0	0	0	0	1	0	0	1	0	0
	100,000-199,999	6	0	0	1	1	1	2	0	2	1	0	1	1	1	1	0	1	0	0	0	0	0	0	0	0
	20,000- 99,999	10	0	0	6	4	2	6	0	11	0	0	4	4	2	6	0	1	0	0	1	0	0	1	0	1
	10,000- 19,999	4	1	0	2	2	0	0	0	4	0	0	0	4	2	1	0	1	0	0	0	0	0	0	0	0
	Under 10,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-Total		28	1	0	11	10	3	11	0	20	1	0	7	9	5	13	0	3	0	0	2	0	0	2	0	1
Midwest	200,000+	4	0	0	2	0	0	3	1	3	0	0	0	1	1	3	0	0	0	0	1	1	0	2	0	1
	100,000-199,999	6	1	0	4	1	1	4	1	5	0	0	0	1	1	5	0	1	0	0	0	0	0	0	0	0
	20,000- 99,999	16	4	1	7	4	2	9	4	13	1	1	2	8	4	14	0	5	0	0	0	0	0	1	0	2
	10,000- 19,999	7	0	0	2	2	0	2	0	7	0	0	0	2	1	6	0	1	0	0	0	0	0	1	0	0
	Under 10,000	2	0	0	0	0	1	0	1	2	0	0	0	1	1	1	7	0	0	0	0	0	0	0	0	0
Sub-Total		35	5	1	15	7	4	18	7	30	1	1	2	13	8	29	7	7	0	0	1	1	0	4	0	3
Southwest	200,000+	7	2	0	5	3	0	6	3	6	0	0	2	3	1	5	0	0	0	0	0	0	0	0	0	0
	100,000-199,999	2	0	0	1	0	0	0	0	3	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0
	20,000- 99,999	10	2	0	4	3	0	2	0	8	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0
	10,000- 19,999	4	0	0	3	0	0	0	0	3	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	1
	Under 10,000	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-Total		25	4	0	13	6	0	8	3	21	0	0	2	7	2	16	0	0	0	0	0	0	0	0	0	1
West	200,000+	7	2	0	5	3	3	7	0	7	3	0	3	3	2	6	0	3	0	0	2	1	0	2	0	2
	100,000-199,999	8	1	0	3	2	1	4	0	7	0	0	1	4	2	8	0	3	0	0	0	1	0	1	0	0
	20,000- 99,999	30	11	0	11	8	0	13	0	23	7	0	1	13	2	16	0	3	0	0	0	0	0	0	0	0
	10,000- 19,999	11	6	0	2	5	1	3	0	7	2	1	0	4	5	4	1	1	0	0	0	1	0	0	0	0
	Under 10,000	3	0	0	0	1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Sub-Total		59	20	0	21	19	6	27	0	45	12	1	5	24	11	35	1	10	0	0	2	3	0	3	0	2
Canada	200,000+	4	0	0	0	1	1	2	0	1	0	0	0	1	1	2	0	0	0	0	0	1	0	1	0	0
	100,000-199,999	2	2	0	0	2	1	1	0	1	0	0	0	2	0	1	0	2	0	0	0	0	0	0	0	0
	20,000- 99,999	10	3	0	0	4	0	4	0	3	1	0	0	7	0	6	0	2	0	0	0	1	0	1	0	6
	10,000- 19,999	3	1	0	0	1	0	1	0	0	0	0	0	2	1	3	0	0	0	0	0	1	0	1	0	0
	Under 10,000	2	0	0	0	1	0	0	0	2	0	0	0	1	0	1	0	2	0	0	0	0	0	0	0	0
Sub-Total		21	6	0	0	9	2	8	0	7	1	0	0	13	2	13	0	6	0	0	0	3	0	3	0	0
Total		213	47	2	71	62	17	97	13	154	7	3	21	91	31	143	2	45	4	1	6	15	1	26	0	25

[1] Note: Not all agencies in each group reported data.

Up to about 30 years ago, cement mortar was commonly used to make sewer pipe joints. As attention began to be given to preventing infiltration and root intrusion into sanitary sewers, it became evident that mortar was not a good material for this service. Such joints were subject to shrinking and cracking; they were rigid and tended to break loose from pipe bells and spigots; they swelled because of hydrogen sulfide action and caused the rupture of pipes; they were the cause of root intrusion. To overcome these problems, various forms of asphaltic compound joints came into use, some hot-poured and some pre-cast. These materials provided desired characteristics, but they required care and skill in application to assure watertightness.

Finally the "O" ring joint was developed. First used on asbestos-cement pipe, it then was found suitable for concrete and vitrified clay by casting a plastic ring on the spigot of the pipe and a plastic lining on the pipe's bell. "O" ring joints also were made applicable to concrete pipe.

ASTM specification C-425, stipulating the characteristics of a satisfactory joint for bell and spigot vitrified clay pipe; other ASTM specifications have been adopted for other pipe materials.

Manufacturers of plain-end vitrified clay pipes have developed a resilient sleeve clamp for pipe ends fastened by non corrosive metal bands; this reportedly makes an effective joint for plain-end pipe.

Field practice indicates that the bottom of a sewer trench is not the most ideal place to form a joint. Jointing under such in-the-wet and often difficult-to-see circumstances does not lend itself to precise and careful workmanship.

Experience has shown that joints for pipes made of PVC are particularly difficult to make where extraneous materials such as sand and water are present. Pipes made of ABS have not demonstrated as much difficulty in achieving a good joint under poor trench conditions.

Some contractors interviewed by investigators suggested that when adverse trench conditions are encountered that an assembled joint, rather than a joint which must be formed, should be used. Figure 2, Chemical Weld Joint, shows such a joint being prepared.

Selection of Sewer Joints

The national investigation in representative jurisdictions, involving in-depth surveys by visiting APWA engineering research personnel, indicated that engineering designers, municipal administrative officials, and contractors wish to use effective joint materials. Of the 26 jurisdictions, 24 reported using "O" ring design; their experience confirmed the effectiveness of this method of jointing. Other jurisdictions reported use of neoprene gaskets; some indicated the use of this type of material without noting that it took the form of an "O"-type ring. Several officials referred to the use of the ASTM specifications C-425 for vitrified clay and sewer pipe and C-361 for concrete and asbestos-cement pipe. The great majority of the jurisdictions reported using one or more of the "O" ring, rubber ring, or C-425 types of joints. Sixteen said they use mortar joints primarily on reinforced concrete pipe. In some cases a form of gasket is employed for watertightness, with spaces in the joint to be filled in with mortar. Figure 3, Compression Gasket Joints, shows three types of compression gasket joints.

Table 2, previously referred to in connection with types of pipe in service, also contains summary

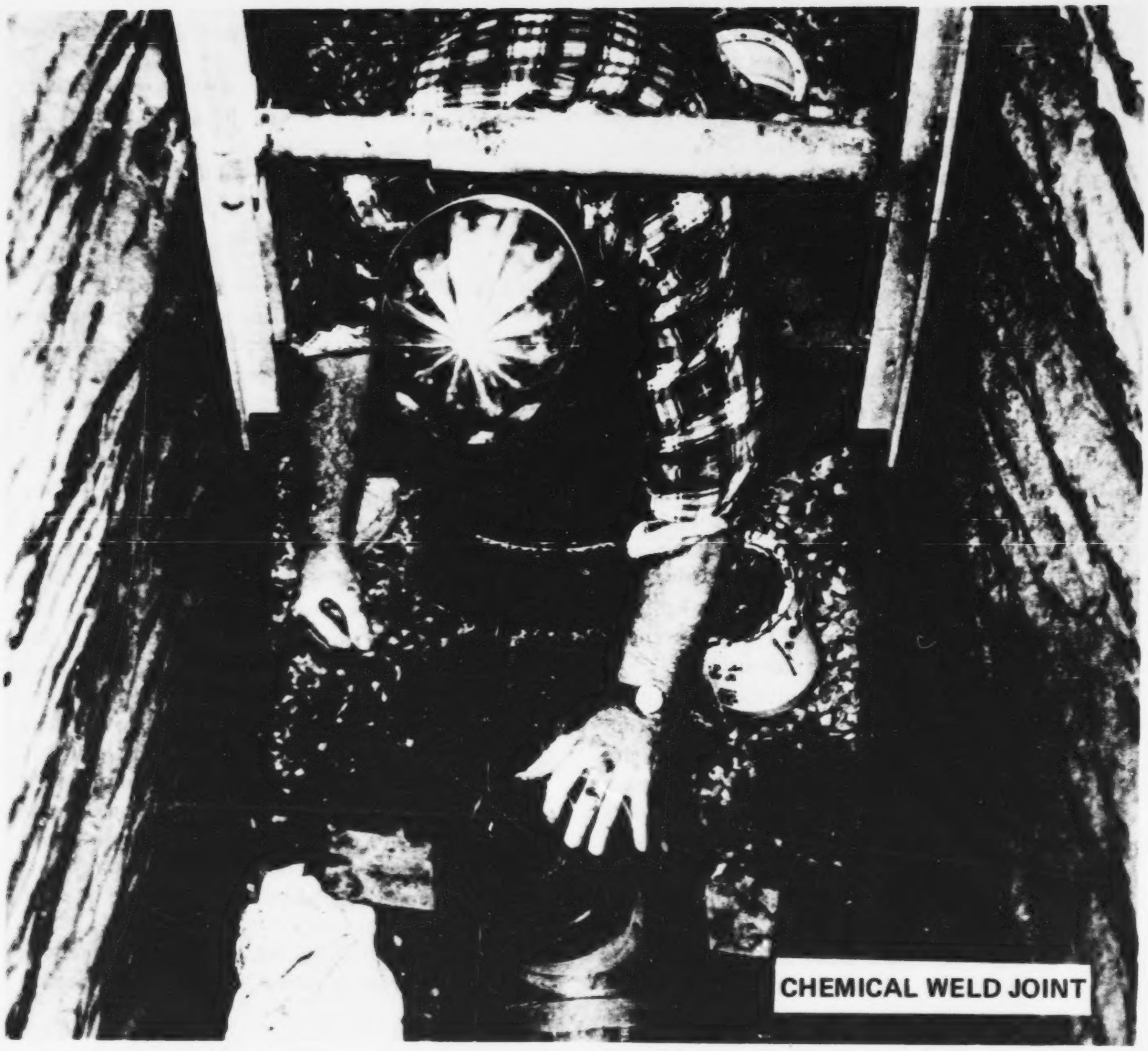
TABLE 7

NATIONAL STATISTICAL SURVEY
SEWER JOINTS IN PLACE
Number of Agencies Reporting type of Sewer Joint Material in Use on Existing Sewer Systems (1)

	Separate Sanitary						Separate Storm						Combined Sewers					
Regions	Bituminous	Mortar	Plastic	Poured	Comp. Gasket	Other	Bituminous	Mortar	Plastic	Poured	Comp. Gasket	Other	Bituminous	Mortar	Plastic	Poured	Comp. Gasket	Other
East	25	28	9	12	30	2	21	32	1	2	18	0	18	9	3	3	12	1
South	19	18	11	11	26	0	6	22	6	6	14	0	0	2	0	0	2	0
Midwest	17	22	14	16	24	2	10	25	1	4	12	4	2	9	0	2	5	0
Southwest	11	15	9	11	17	1	1	14	2	1	7	2	0	1	0	0	1	0
West	14	49	25	14	42	10	4	38	3	4	23	13	1	10	1	1	8	3
Canada	9	10	0	2	12	1	4	13	0	2	7	1	1	7	0	2	2	2
Totals	95	142	68	66	151	16	46	144	13	19	81	20	22	38	4	8	30	6

(1)Note: Not all agencies have each type of sewer system

FIGURE 2



Courtesy: United Technology Center

TABLE 6
CONSULTING ENGINEERS SURVEY
JOINTING MATERIALS

Number of Firms Reporting by Type of Sewer Joint Material Used

Pipe Material	Rubber "O" Ring	Rubber Gasket	Mechanical	Molded P.V.C.	Bituminous	Other
Asbestos-Cement	39	6	–	–	–	–
Cast Iron	20	17	21	8	–	1 Lead
Concrete	41	20	–	–	1	–
Plastic	9	3	–	–	–	21 Solvent Weld
Reinf. Concrete	–	2	–	–	–	–
Steel	6	3	8	–	–	14 Welded
Vitrified Clay	19	5	–	40	2	–

information on the types of joints used in sewer pipe construction in the 26 jurisdiction areas covered by the representative on-site investigations.

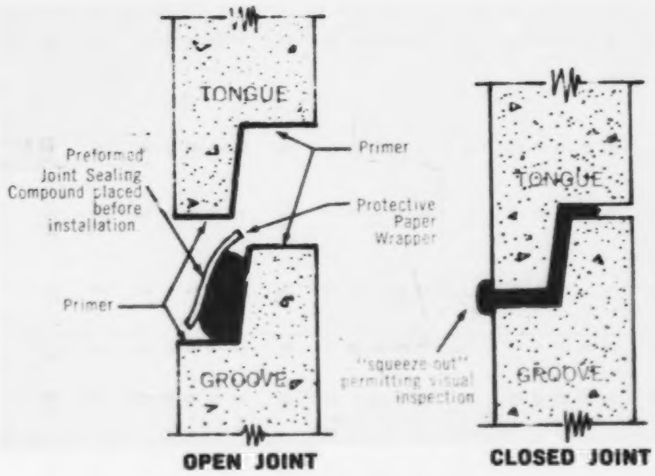
The consulting engineering firms responding to the survey inquiry indicated an overwhelming preference for the "O" ring type of joints with all applicable types of pipe. A summary tabulation of these results is contained in Table 6, Consulting Engineers Survey – Jointing Materials.

There may be some confusion in reporting rubber "O" ring and rubber gasket. At any rate, these two classifications were most frequently reported, except on vitrified clay, in which case molded PVC was specified with twice the frequency.

As in the case of sewer pipe material, the national statistical survey requested information on joints now in place and now being specified. Significantly, where 142 jurisdictions had utilized mortar joints in their existing system, only 23 now specify this type. This is dramatic evidence of a change in jointing practices. Bituminous jointing material similarly has been dropped from many specifications while usage of plastic and rubber "O" rings has increased. The complete results are shown in Table 7, National Statistical Survey – Sewer Joints in Place, and Table 8, National Statistical Survey - Sewer Joints. Specified.

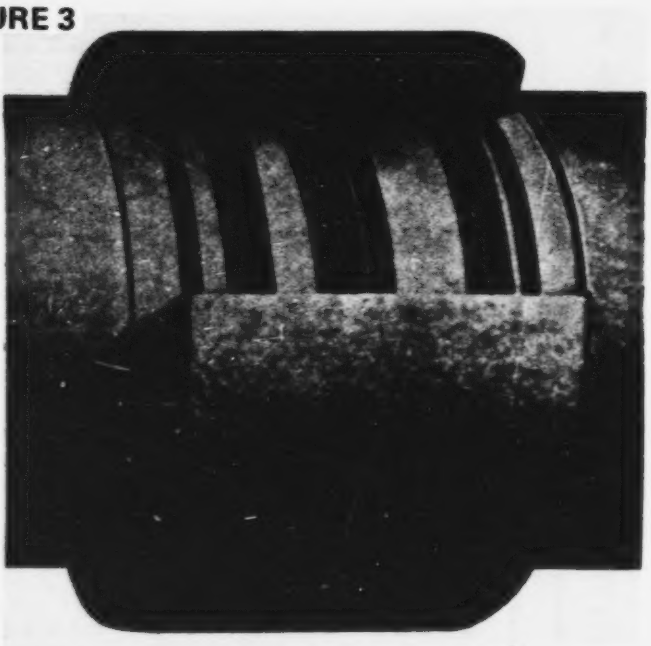
The survey disclosed one striking consensus: consulting engineers are unanimous in the opinion that infiltration has decreased markedly in recent years because of improvements in pipe manufacture and joint materials.

FIGURE 3


TONGUE
Preformed Joint Sealing Compound placed before installation
Primer
Protective Paper Wrapper
Primer
GROOVE
OPEN JOINT
TONGUE
"squeeze out" permitting visual inspection
GROOVE
CLOSED JOINT

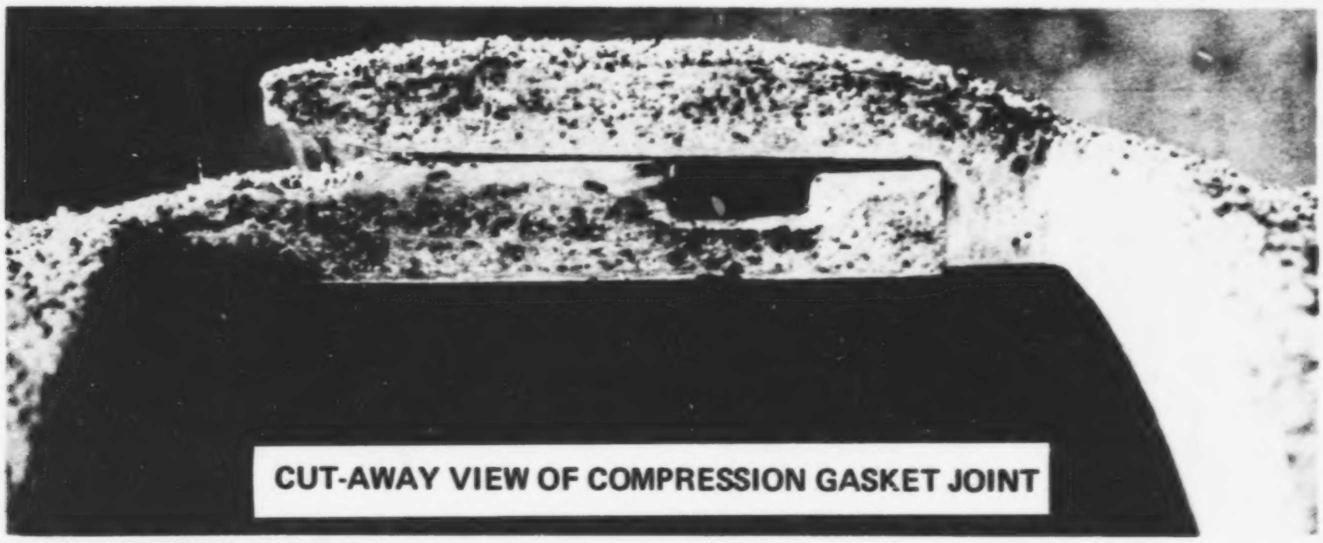
Courtesy K. T. Snyder Co., Inc.

CONCRETE TONGUE AND GROOVE PIPE



Courtesy Certain-teed Products Corp.

DOUBLE COMPRESSION GASKET ASBESTOS-CEMENT PIPE



CUT-AWAY VIEW OF COMPRESSION GASKET JOINT

Courtesy: United Technology Center

TABLE 8

NATIONAL STATISTICAL SURVEY
SEWER JOINTS SPECIFIED
Number of Agencies Reporting Type of Sewer Joint Material Specified by Type of Sewer System*

			Separate Sanitary							Separate Storm							Combined Sewers						
Region	Population Groups	Number[1] in Group	Bituminous	Mortar	Plastic	Poured	Rubber Ring	Other	NA	Bituminous	Mortar	Plastic	Poured	Rubber Ring	Other	NA	Bituminous	Mortar	Plastic	Poured	Rubber Ring	Ot.er	NA
East	200,000+	9	2	0	2	0	4	0	2	3	2	1	0	4	0	1	3	0	2	0	4	0	1
	100,000-199,999	7	2	3	2	1	7	0	0	2	6	1	1	4	0	1	0	1	0	0	2	0	4
	20,000- 99,999	23	5	3	7	5	20	2	1	5	10	1	1	13	1	3	2	2	1	2	7	1	14
	10,000- 19,999	5	1	0	0	0	4	0	0	3	3	0	1	2	0	0	0	0	0	0	1	0	4
	Under 10,000	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Sub-Total		45	10	6	11	6	36	2	3	13	22	3	3	23	1	5	5	3	3	2	14	1	24
South	200,000+	8	0	0	2	0	7	0	0	0	2	0	1	6	0	0	0	0	0	0	2	0	6
	100,000-199,999	6	0	2	3	3	4	0	0	0	2	2	2	2	0	2	0	0	0	0	0	0	6
	20,000- 99,999	10	0	1	5	2	10	0	0	0	5	5	1	5	0	3	0	0	0	0	0	0	10
	10,000- 19,999	4	1	2	1	2	5	0	0	1	2	1	0	3	0	1	0	0	0	0	0	0	4
	Under 10,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-Total		28	1	5	11	7	26	0	0	1	11	8	4	16	0	6	0	0	0	0	2	0	26
Midwest	200,000+	4	0	0	3	0	3	0	1	1	2	0	0	2	0	1	0	1	2	0	2	0	2
	100,000-199,999	6	0	0	4	1	4	0	0	3	2	0	0	3	0	0	0	0	0	0	0	0	6
	20,000- 99,999	16	3	0	5	3	9	0	1	7	9	1	0	7	0	0	2	1	0	0	2	0	11
	10,000- 19,999	7	1	0	2	0	6	0	0	1	4	1	0	3	0	1	0	0	0	0	0	0	7
	Under 10,000	2	0	0	0	0	1	0	1	0	1	0	0	1	0	0	0	1	0	0	0	0	1
Sub-Total		36	4	0	14	4	23	0	3	12	18	2	0	16	0	2	2	3	2	0	4	0	27
Southwest	200,000+	7	1	1	4	2	6	2	0	2	3	2	0	3	1	0	0	0	0	0	0	0	7
	100,000-199,999	2	0	0	1	1	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2
	20,000- 99,999	10	0	0	3	1	10	0	0	2	5	2	0	4	0	4	0	0	0	0	0	0	10
	10,000- 19,999	4	0	1	2	0	1	0	1	0	1	0	0	0	0	3	0	0	0	0	1	0	[illegible]
	Under 10,000	2	0	0	0	0	1	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	2
Sub-Total		25	1	2	10	4	19	2	2	4	11	4	0	7	1	9	0	0	0	0	1	0	24
West	200,000+	7	1	1	5	2	6	2	0	0	2	2	1	4	1	2	0	0	1	1	2	0	5
	100,000-199,999	8	0	1	4	1	6	1	0	0	3	2	0	4	3	0	0	0	0	0	1	0	7
	20,000- 99,999	30	1	2	15	2	21	4	4	2	17	3	1	10	4	10	0	0	0	0	0	0	32
	10,000- 19,999	11	0	0	6	0	9	2	0	0	4	2	0	6	3	2	0	0	0	0	1	1	10
	Under 10,000	3	0	1	1	0	2	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	3
Sub-Total		59	2	5	31	5	44	9	4	2	27	9	2	24	12	15	0	0	1	1	4	1	57
Canada	200,000+	4	0	1	0	1	1	1	0	0	2	0	1	1	1	0	1	1	0	0	0	1	1
	100,000-199,999	2	1	0	0	0	2	0	0	0	2	0	0	1	0	0	0	0	0	0	1	0	1
	20,000- 99,999	10	1	2	0	0	7	0	0	2	6	0	0	4	1	0	0	0	0	0	1	1	8
	10,000- 19,999	3	1	1	0	0	2	0	0	1	1	0	0	1	0	0	0	0	0	0	1	0	2
	Under 10,000	2	2	1	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	2
Sub-Total		21	5	5	0	1	12	1	0	5	13	0	1	7	2	0	1	1	0	0	3	2	14
Total		213	23	23	77	27	160	14	11	37	102	26	10	93	16	36	8	7	6	3	28	4	155

(1) Note: Not all agencies in each group reported data

* Note: Not all agencies have each type of sewer system

Design Considerations

Sewer design should be a well-developed technique after many years of refinement and experience. However, although hydraulic and structural design of conduits has been researched thoroughly and perfected, designers and sewer system administrators and operators still have basic differences of opinion on the proper practices to control excessive infiltration.

While many of these points of difference are related to general sewer design, they have a direct bearing on infiltration control. That is because basic design and construction practices may affect the integrity of the system and, hence, the amount of infiltration during service. One point of great significance came to light during the national study: the vital need for preplanning funds prior to actual design, to determine soil and ground water conditions and existing sources of infiltration and their effect on pumping and treatment facilities. Presently, local, state, and Federal agencies do not fully recognize the basic importance of adequate review and evaluation of existing facilities and proper planning before adding new sewer system facilities. The inadequacies in preplanning practices, as well as in actual design procedures, include:

1. Average and peak design flows too often are calculated on the basis of standard textbook criteria unrelated to the actual conditions for the area under design.
2. The units used to delineate design flows vary widely and at times seem inappropriate for separate sanitary sewer design. As an example, the correlation between "gallons per acre per day" and actual sanitary sewage flows often is indeterminate.
3. Too much sewer design is undertaken without adequate subsurface knowledge or investigation.
4. There is inadequate communication and a lack of understanding between sewer design engineers and sewer maintenance personnel. Designers, unfortunately, are not always aware of the in-the-field problems of maintenance; conversely, maintenance staffs solve daily sewer surcharge difficulties by use of "seat-of-the-pants" expedients which very often are not reported to the sewer officials or design engineers.
5. The design engineers too frequently have their association with a project severed after they review the bids. Often there is no continuity between design decisions and the most critical phase – the construction phase.

Design Criteria

When asked if control of excessive infiltration was a problem in their design work, two-thirds of the consulting engineering firms participating in the survey answered "yes" and one-third "no." These opinions may support the national survey of statistically chosen and surveyed jurisdictions in its findings that some sections of the country do not experience the ground water or rainfall conditions which make infiltration an overriding consideration in either sewer design or maintenance. These consulting engineers' findings may indicate a need on the part of designers for more positive recognition of the problem of infiltration. Betokening this need is the awareness that service and maintenance personnel, contractors, and pipe manufacturers show toward that problem.

The consulting engineers were asked if the allowances they used for infiltration/inflow in sewer capacity design were different from those for infiltration in specific sewer construction projects. The responses were equally divided between "yes" and "no." They reflected a lack of consistency on the basic concept of design flow for sanitary sewers. The same inconsistency was demonstrated in the responses from jurisdictions surveyed for the purpose of determining statistical averages that would represent national practices in infiltration prevention and control. Data covering the national survey will be discussed later.

Table 9 presents a summary of the Consulting Engineers Survey – Sewer Infiltration Design Allowances. The 66 firms responding to the survey reported the use of 35 different sewer design standards or infiltration allowances. These varied from "none" to amounts such as 15,000 gallons per mile per day. They gave clear evidence of limited standardization.

The survey indicated considerable confusion over the terminology and measurement units for infiltration allowances. Some design engineers seem to feel that infiltration *design* allowances and infiltration *construction* allowances are one and the same. Others indicate they are completely different and should be stipulated by different units and standards of measurement.

The national statistical survey provided data on similar facets of sewer design and construction pertinent to infiltration conditions and control practices.

As discussed previously, considerable variation in units and terminology also was indicated in jurisdictions replying to this survey. The survey showed the use of total peak flow allowances and

TABLE 9
CONSULTING ENGINEERS SURVEY
SEWER INFILTRATION DESIGN ALLOWANCES

United States Responses	Number of Replies
None	1
Included in gpcd	1
No answer	7
Variable	2
500 gpad	2
500–2,000 gpad	1
1,000–1,200 gpad	1
15,000 gpmd (8 in.)–20,000 gpmd (18 in.)	1
90 gpcd + 10-20 gpcd for infil./inflow	1
Not applicable	6
500–1,000 gpad	3
4 times normal sanitary flow	2
Formula	1
500 gpimd	4
300–2,000 gpad	2
100 gpcd	3
.0088 cfs/a	1
1,600–3,500 gpad	1
200–400 gpcd	2
500–700 gpad	1
40 gpi/1,000 ft.	1
133–250 gpimd	1
400–6,000 gpad	1
2½ times sanitary flow	1
250 gpimd	1
200 gpimd	1
ASCE recommendation	1
30 gpcd additional	1
.1–.3 cfs/100a	1
125 gpimd	1
Not permitted by State	1
30 gal./acre/unit Density	1

Canadian Responses	Number of Replies
No inflow allowed	1
.004 cfs/a	1
Varies	3
300 gpcd + 1,000 gpad	1
.002–.004 cfs/a	1

Note: These abbreviations are used for Tables 9, 10, 11, 12 and 13.

a–Acre
adf–Average daily flow
cfs–Cubic feet per second
cfs a–Cubic feet per second per acre
dia–Diameter
DU–dwelling unit
dwf–Dry weather flow
ft–Foot
gpad–Gallons per acre per day
gpcd–Gallons per capita per day
gpid-Gallons per inch diameter
gpimd–Gallons per inch-mile per day
gpmd–Gallons per miles per day
Imp–Imperial gallons
NA–Not applicable
x–Times

typical construction type standards. Some criteria were related to drainage areas and some to pipe size and length; a few were based on per capita contribution, and a number on percentage relatioship of dry weather to average flow. When almost 100 different criteria are reported by some 200 jurisdictions, it is evident that little standardization is in effect. Part of the problem lies in indistinctly defined concepts – first, of design allowances in general, and second, of infiltration or total extraneous water allowances in particular. Table 10, National Statistical Survey – Infiltration Design Allowances, records the current practice by region and population in the United States and Canada.

Construction Considerations

The physical environment in a 10- or 20-feet-deep sewer trench, with water, mud, silt, and debris, coupled with excessive cold or heat, does not lend itself to optimum human or material performance in joint construction. Years ago, in the use of mortar or poured joints, many incomplete ones were left in the ground after construction. Today, even with relatively workable and effective jointing techniques, TV inspection cameras still find joint materials omitted or misplaced and the defective joints subject to unimpeded entry of ground water or exfiltration of waste waters. The only insurance against poor construction is vigilance and unremitting control. Positive steps which should be taken, include:

1. Provide funds for adequate preliminary investigation of soils, ground water, foundation, and condition of existing system;
2. Recognize the relationship between design and the problems of maintenance;
3. Keep the design engineer in the picture – making him responsible for placing his design into full and efficient operation without infiltration;
4. Control quality of all phases of construction and inspection;
5. Provide adequate and constant inspection by personnel responsible to, and paid by, the owner;
6. Test short sections of pipe frequently for acceptance by the owner;
7. Use TV or photographic checking and recording of sewer interiors as an inspection technique, paid for by the owner;
8. Require that all repairs and correction be made at the contractor's expense before connection of building sewers;
9. Check on all repairs by TV or photography at contractor's expense, and
10. Inspect, correct, and accept small sections as they are completed so that the entire system can be checked for tightness, unit-by-unit, rather than by a total test at the end of construction.

Table 11, Consulting Engineers Survey – Infiltration Construction Allowances, lists the construction allowances used by 66 firms. In contrast to the design allowances summary, Table 11 indicates there is more consistency in the units of infiltration volumes, although there still is wide variation in actual allowances. By far the most commonly used allowance standard is 500 gallons per inch of pipe diameter per mile per day. This allowance gained technical credence when first used in the so-called "Ten-States Standards." It is significant that the states involved in developing these design criteria for sewage works facilities intended them to be a guideline rather than a standard. Nevertheless, the 500-gallon allowance has been widely adopted by many states, jurisdictions, and consulting firms.

Fortunately, unquestioned acceptance of the 500-gallon criterion is being superseded by lower and more realistic design and construction allowances, based on the greater potential infiltration control capabilities of new products, better inspection and testing procedures, and greater control of construction methods. The consulting engineers' survey confirmed this new and important trend.

The infiltration construction allowances reported by the 212 jurisdictions in the United States and Canada are listed in Table 12, National Statistical Survey – Infiltration Construction Allowances. The results, as expected, are similar to the consultant's data, since most jurisdictions are served by consultants in this area of sanitary engineering criteria. Here again, there are fewer different allowances for construction than for design, and more uniformity of terminology. The concept of checking compliance with an infiltration construction allowance, as a condition for acceptance, is quite universally recognized and used. The use of allowances for excess flows in sewer system design may be recognized, but there is little uniformity in approach and results.

Once again, the "Ten-States Standards" of 500 gallons per inch of diameter per mile per day is the most frequently used. This standard is found in all regions and all population groups.

Water pollution control agencies of the 50 states and eight Canadian provinces revealed an even greater

TABLE 10

NATIONAL STATISTICAL SURVEY INFILTRATION DESIGN ALLOWANCES

Number of Agencies Reporting Infiltration Design Allowances by Population Group

Population		Over 200,000		100,000-199,999		20,000-99,000		10,000-19,999		Under 10,000
Region	No.	Allowance	No.	Allowance	No.	Allowance	No.	Allowance	No.	Allowance
East	4	no ans.	2	no ans.	16	no ans.	3	no ans.	1	10,000 gpmd
	1	no design allowance	1	no design allowance	1	no design allowance				
	1	2.5 × dwf	1	10 gpcd	1	varies	1	30 gpcd		
	1	5,000 gpad	1	3,000 gpad	1	- 0 -				
	1	1,000-1,500 gpad	1	10,000 gpmd	1	5 x dwf				
	1	19,556 gpad	1	400 gpd (no units given)	1	15% dwf	1	2,000 gpad		
					1	200 gpimd				
					1	5,000 gpmd				
South	1	no ans.	1	no ans.	3	no ans.	3	no ans.		
	1	85% dwf	1	30% dwf	1	100% dwf	1	20% dwf		
	1	250% dwf	1	25 gpcd	1	225% dwf				
	1	0.4 cfs a	1	100 gpcd	1	20 gpcd				
	1	300 gpimd	1	300 gpad	2	500 gpimd				
	1	400-750 gpimd	1	750 gpad	1	0.0015 cfs a				
	1	15,000 gpmd			1	2,640 gpmd				
	1	25,000 gpmd								
Midwest	1	no ans.	1	varies	1	- 0 -			1	no ans.
	1	20 gpcd	2	400 gpimd	8	no ans.	7	no ans.	1	2,000 gpmd
	1	65 gpcd	2	500 gpimd	2	10% dwf				
	1	0.013 cfs a	1	0.01 cfs a	1	20% dwf				
			1	1,000 gpimd	1	4 x dwf (under 8 in. diameter) 2.5 x dwf (18-42 in. diameter) 1.5 x dwf (over 42 in. diameter)				
					1	2.4 gph 1,100 ft.				
					1	100 gpcd				
					1	1,000-1,500 gpad				
					1	200 gpimd				
					7	300 gpimd				
					2	500 gpimd				
Southwest	1	no design[2] allowance	1	2.5 – 4 x dwf	2	no ans.	1	no ans.	1	no ans.
	1	50% dwf	1	1,500 gpad	1	- 0 -	1	no design allowance	1	no design allowance
	1	100 gpcd			1	50% dwf	1	10% dwf		
	1	750 gpad			1	317 gpimd	1	100 gpcd		
	1	1,500-3,000 gpad			3	500 gpimd				
	2	500 gpimd			1	650 gpimd				
					1	750 gpimd				
West	1	- 0 -		no ans.	12	no ans.	5	no ans.	1	no ans.
	1	no ans.	2	no ans.	3	no design allowance	4	no design allowance	2	no design allowance
	1	20% dwf	1	100% dwf	2	10% of capacity	1	507 gpimd		
	1	600-2,000 gpad	1	100-300% dwf	1	50% dwf	1	12,672 gpmd		
	1	1,100 gpad	1	30 gpcd	1	3 x dwf				
	1	1,350 gpad above g.w. table 2,750 gpad below g.w. table	1	634 gpimd	1	250 gpad				
	1	0.001-0.003 cfs a	1	22,222 gpmd	1	500 gpad				
					2	1,000 gpad				
					1	1,100 gpad				
					1	5,000 gpad				
					1	10,000 gpad				
					3	500 gpimd				
Canada	1	no ans	1	0.002 cfs a	1	no ans.	1	no ans.	1	no ans.
	2	no design allowance	1	0.009 cfs a	1	no design allowance	1	no design allowance	1	no ans.
	1	200 gpad			1	12 gpimd	1	3 x dwf		
					2	300 gpad				
					1	2,000 gpad				
					1	0.00156 cfs a				
					1	1,500 gpimd (imp)				
					1	1,667 gpimd (imp)				
					1	1,300 gpad (imp)				

NOTE 1. Some allowances which were given for less than a day or for less than a mile have been converted to amounts per mile per day.

NOTE 2. Where no design allowance are reported, it implies that agency has not established or does not use a standard criteria for design. This may be because of the use of combined sewers, or because all design is by consultants who are allowed to use their own criteria.

TABLE 11
CONSULTING ENGINEERS SURVEY
INFILTRATION CONSTRUCTION ALLOWANCES

United States Responses	Number of Replies
No answer	2
1,000 gpimd	1
500 gpimd	15
50 gpi/1,000 ft./day	1
.1 gal/in/1,000 ft./day	1
600 gpimd	1
15,000 gpimd–20,000 gpimd	1
200 gpimd	7
1250 gpad-uplands; 2750 gpad-lowlands	1
100 gpimd	6
None	2
350 gpimd	1
100 gpi/1,000 ft./day	1
250 gpimd	5
200–500 gpimd	2
Ten states	1
10 gpi/100 ft./day	1
40 gpi/1,000 ft./day	1
.2 gpi/100 ft./day	1
150 gpimd	3
245 gpimd	1
50 gpimd	1
125 gpimd	1
50–100 gpimd	1
300 gpimd	1
Canada Responses	
a formula	1
200 gpimd	1
.004–.0032 cfs	1
312 gpimd	1
No ans.	1
.2–.8 gpi/100 ft./hr.	1

reliance on the allowance of 500 gallons per inch of diameter per mile per day. This is understandable since that figure originally was set as a guideline by representatives of a number of state agencies. Thirty-two states and provinces stipulate this allowance, showing how such guidelines evolve into standards and are adopted by many contiguous jurisdictions. Surprisingly, 11 jurisdictions do not, or have not, set any standards for allowable infiltration. Table 13, State and Provincial Survey – Infiltration Allowances, lists these survey results.

In view of the importance of full control over sewer construction if infiltration is to be held to a minimum, consultants were asked if they were retained to supervise construction of the systems they design. Ninety-five percent reported they had been so retained. This figure must be contrasted with the findings of interviewers who made in-depth

TABLE 12

NATIONAL STATISTICAL SURVEY INFILTRATION CONSTRUCTION ALLOWANCES

Number of Agencies Reporting Infiltration Construction Allowances by Population Group

Population		Over 200,000		100,000-199,999		20,000-99,000		10,000-19,999		Under 10,000
Region	No.	Allowance	No.	Allowance	No.	Allowance	No.	Allowance	No.	Allowance
East	1	no ans.	1	no ans.	10	no ans.			1	3000 gpmd
	3	no const. allowance[2]	1	250 gpimd	3	no const. allowance	1	no const. allowance		
	1	53 gpimd	1	360 gpimd	1	1 gpmd	1	50 gpimd		
	1	150-300 gpimd	1	500 gpimd			1	200 gpimd		
	1	300 gpimd	1	2,000 gpmd	1	150 gpimd	2	500 gpimd		
	1	500 gpimd	1	5,000 gpmd 8" 10,000 gpmd (max)	1	200 gpimd				
	1	634 gpimd	1	200 gpd (no units given)	1	300 gpimd				
					4	500 gpimd				
					1	792 gpimd				
					1	5,000 gpmd				
South	1	no ans.			4	no ans.	2	no ans.		
	2	250 gpimd	2	100 gpimd			1	500 gpimd		
	1	300 gpmd	1	300 gpimd	1	200 gpimd	1	30,000 gpmd		
	2	500 gpimd	1	500 gpimd	3	500 gpimd				
			1	520 gpimd	1	500 gpimd (to 30 in. diam.) 9,000 gpimd (over 30 in. diam.)				
	1	10,000 gpmd	1	1,320 gpimd	1	1,320 gpimd				
Midwest	2	no const. allowance	2	no ans.	5	no ans.	5	no ans.	1	no ans.
	1	0.003 cfs a	1	200 gpimd	1	7,850 gpmd	1	400 gpimd	1	10,000 gpmd
	1	400 gpimd	1	250 gpimd	1	100 gpimd	1	5 gal/day/sq.yd. of interior surface		
			2	500 gpimd	2	200 gpimd				
					1	300 gpimd				
					10	500 gpimd				
					1	1,000 gpimd				
Southwest	2	no const. allownace	1	no ans.	3	no ans.	2	no ans.		
	2	250 gpimd	1	400 gpimd	2	no const. allowance	1	no const. allowance	1	no const. allowance
	1	500 gpimd			1	- 0 -	1	10,000 gpmd	1	Okla. state
	1	1,000 gpimd			2	500 gpimd				
	1	10,000 gpmd			1	Okla. state[1]				
West	1	no ans.	4	no ans.	14	no ans.	5	no ans.	1	no ans.
	1	5% dwf	1	no const. allowance	2	no const. allowance	1	no const. allowance	2	no const. allowance
	1	0.001-0.003 cfs a	1	190 gimd x $\sqrt{H}$	1	1,100 gpmd	1	0.1 gpd/sq ft of wetted surface		
	2	500 gpimd	1	100 gpimd	1	10,000 gpmd	1	190 gimd x $\sqrt{H}$		
	1	507 gpimd	1	0.00619 cfs a	1	100 gpimd	1	507 gpimd		
	1	[3168 + 50 D in.)] gpmd			7	500 gpimd	1	637 gpimd		
					1	634 gpimd	1	1,267 gpimd		
					2	760 gpimd				
					1	−190 gpimd x $\sqrt{H}$				
Canada	1	none			3	no ans.	1	no ans.		
	1	158 gpimd (imp)	2	no const. allowance	2	no const. allowance	1	no const. allowance	1	no ans.
	1	500-1,000 gpimd (imp)			1	12 gpimd	1	3 x dwf	1	792-1,056 gpimd (imp)
	1	634 gpimd (imp)			1	240 gpimd (imp)				
					1	500 gpimd (imp)				
					1	3,168 gpmd				
					1	1,500-2,000 gpad				

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[1] Some allowances which were given for less than a day or for less than a mile have been converted to amounts per mile per day.

[2] Where no design allowances are reported, it implies that agency has not established or does not use a standard criteria for design. This may be because of the use of combined sewer, or because all design is by consultants who are allowed to use their own criteria.

TABLE 13

STATE AND PROVINCIAL SURVEY INFILTRATION ALLOWANCES

Allowance	No. Reporting Agencies
1,000 gpimd	1
650 gpimd	1
500 gpimd	32
300 gpimd	3
250 gpimd	1
.25 Imp. gal./in. dia./100 ft./day	1
10,000 gpmd	2
New England Interstates Guides	1
ASTM – C425-66T	1
Relatively tight	1
Varies	3
Standards not set	11

in-the-field investigations of practices in the 26 representative jurisdictions chosen for this type of research. They indicated the designers often are not the individuals who make inspections or are kept apprised of the construction inspection experiences. Closer liaison is needed between those who design and those who supervise construction of design concepts, even though separate staffs of jurisdictions or consulting firms carry out the two functions.

Another question explored with consultants was whether or not sewers, after laying and inspection, are found to comply with infiltration construction allowances. All the firms replied in the affirmative, although many answers were qualified with references to "after correction." Obviously, for a construction project to be completed and accepted, the system must pass some form of test and inspection. This means that infiltration construction allowances must be met although their severity and strictness may vary considerably. The problem of acceptance suggests another consideration: that the ability of sewer pipe and sewer joints to retain infiltration-free conditions should be determined. A test made a few hours after completion of a sewer line may not be representative of conditions that will exist even a few days later when ground water levels may change, or a few months and years later when differential settlements may occur and deterioration of joints and pipes may take their toll. Infiltration, therefore, is not a static situation. Even the best sewer system may develop leaks after years of service. Good products and good construction practices are the best insurance against such long-term defects.

Consultants reported they seldom vary their design and construction infiltration allowances to meet different soil and ground water conditions. Ninety percent cited no variations to meet soil conditions. Sixty-six percent reported no such variations for ground water conditions. These findings indicated little dependence on the effect construction conditions have on infiltration rates. On the other hand, if basic design and construction criteria take cognizance of the conditions under which sewers will be laid, any further relaxation or tightening of infiltration allowances to meet varying conditions probably would be unnecessary or inadvisable.

Survey Results on Inspection and Testing

The 50 state and eight provincial agencies were asked if they inspect sewer projects for design compliance. Twenty-one said "yes," 34 said "no," and three gave no response.

These state and provincial agencies were asked if their municipalities carry out construction inspection and testing for leakage. Only two reported no such control, but 11 did not respond or indicated they did not know.

The survey results show that the emphasis on testing and inspection lies at the local level, where it properly belongs; but there is need for more interest and activity at higher governmental levels. State agencies reported they do not have adequate staff to become involved in extensive construction inspection.

Sixty-six consulting firms responded to a request for information on the methods of testing they use. Fifty reported infiltration testing, three reported smoke testing, and one listed television inspection methods. It is obvious that many consulting firms utilize more than one method to meet varying conditions which require different test procedures.

The national statistical survey indicated an increasing appreciation of the importance of good inspection and found this type of job control mandatory in a great majority of jurisdictions. The relationship between improved inspectional work and adherence to infiltration requirements is obvious.

Table 14, National Statistical Survey – Construction Inspection, summarizes the responses of more than 212 jurisdictions on the responsibility for inspections. In general, all construction is inspected by someone, and only half those reporting use their consultants for this purpose.

In the national statistical survey, the jurisdictions

TABLE 14

NATIONAL STATISTICAL SURVEY
CONSTRUCTION INSPECTIONS*

Subtotals:	City	Consultants	Not Inspected	No Answer
East	44	19	0	0
South	28	19	0	0
Midwest	34	18	0	0
Southwest	24	11	0	1
West	52	18	0	0
Canada	21	9	0	0
200,000+	39	14	0	0
100,000-199,999	30	14	0	1
20,000- 99,999	94	48	0	0
10,000- 19,999	30	13	0	0
Under 10,000	10	5	0	0
Totals	203	94	0	1

*Many agencies give more than one reply

were asked if new sewer construction is tested for leakage. One hundred and seven reported affirmatively, but 59 had no such control methods and 18 did not answer. The summary of these replies is given by regions and population groups in Table 15, National Statistical Survey – Are Sewers Tested for Leakage?

The 212 jurisdictions were asked to list their methods of testing. Table 16, National Statistical Survey – Testing Methods, presents a summary of responses by regions and population groups. Table 17, National Statistical Survey – Testing Methods, Totals by Population Group, is a compilation of these methods by population groups only. In these tabulations the predominance of exfiltration testing becomes evident. A total of 61 jurisdictions reported use of exfiltration, 43 use infiltration, and 27 specify air testing. The tendency to adopt the new air test procedure seems to be growing. Television inspection also is reported in a number of cases; its application as an inspection tool is wider than for construction testing and sewer acceptance purposes.

Ground Water and Soil Conditions

Ground water levels are the major factor influencing infiltration rates if the sewer structure is not watertight. True, total or partial immersion of a leaking sewer structure in standing ground water offers the greatest hazard of infiltration. However, some infiltration can occur from water held interstitially within the soil or percolating through the soil on its way to the ground water table during a period of precipitation, thaw, or drainage of surface waters.

TABLE 15
NATIONAL STATISTICAL SURVEY
ARE SEWERS TESTED FOR LEAKAGE?

Response By Regions	Yes	No	No Answer
East	32	12	1
South	22	6	0
Midwest	23	10	2
Southwest	14	10	1
West	51	8	0
Canada	6	15	0
Response By Population Groups			
200,000+	25	14	0
100,000–199,999	27	3	1
20,000– 99,999	72	26	1
10,000– 19,999	21	11	2
Under 10,000	3	7	0
Total	148	61	4

TABLE 16

NATIONAL STATISTICAL SURVEY
INFILTRATION TESTING METHODS

Region

Method	East	South	Midwest	Southwest	West	Canada	Total
Exfiltration	14	7	3	7	39	3	73
Infiltration	10	11	12	6	5	3	47
Visual	5	4	4	2	–	–	15
Air	1	–	1	–	23	–	25
TV	–	4	4	–	3	1	12
Smoke	2	4	1	–	–	–	7
Various	1	–	–	–	1	–	2
No Test Used	14	6	8	7	3	15	53
No Answer	4	–	4	7	6	–	21

Note: Not all agencies in each group reported data

TABLE 17

NATIONAL STATISTICAL SURVEY
INFILTRATION TESTING METHODS
Totals by Population Group

Method	Over 200,000	100,000 199,999	20,000 99,999	10,000 19,999	Under 10,000
Exfiltration	11	9	41	10	2
Infiltration	10	13	15	9	–
Visual	3	4	4	4	–
Air	3	3	15	3	1
TV	1	4	6	1	
Smoke	–	2	2	2	
Various	–	–			
No Test Used	11	3	25	9	5
No Answer	4	2	6	6	2

The more than 200 jurisdictions in the national statistical survey were questioned about the percentages of their sewer systems laid in or below ground water tables during dry seasons and wet seasons. Table 18, National Statistical Survey – Percentage of Sewers Reported Below Ground Water Table, summarizes the responses to this inquiry, categorized into five regions of the nation and Canada and five population groups. Regional variations in ground water conditions exist. Many respondents could make no accurate estimate of the percentages of their sewers inundated or partially submerged in ground water.

Figure 4, Well-Point System, is a photograph of a large diameter sewer being laid in the "dry" by use of a well-point system to dewater the trench.

Figure 5, Sewer Construction Under Water, is photographs of 8-inch vitrified clay pipe being laid by skin-divers in a trench which is impossible to dewater because the sewer is laid in coral rock and ground water is extremely high. The pipe was laid on sandbagged stone bedding which is shown on the ditch bank.

Sewers laid in ground water were more prevalent in the East, Midwest, and West, than in the South and Southwest. As might be expected, the areas of the nation with low precipitation conditions reported somewhat less sewer construction in ground water than areas prevailingly wetter. The total responses from the United States and Canada showed that 7 percent have more than 50 percent of their sewer systems under ground water tables during dry weather; 15 percent have over 50 percent of their systems under those tables during wet-weather conditions. In general, very few jurisdictions reported their sewers never were under the ground water table. These results indicate that the primary ingredient for infiltration – water – affects sewer systems in most sections of the United States and Canada, at least during certain periods of the year.

Because of the relationship between ground water levels and precipitation, the jurisdictions involved in the surveys were asked to report their annual precipitation. These data are summarized in Table 19, Annual Rainfall and Maximum Months. In the East, all average rainfall figures were divided between the ranges 21 to 40 inches and 41 to 70 inches.

In the South, a greater percentage of communities reported rainfall in the 41- to 70-inch range. In the Midwest, the total rainfall figures dropped, with the majority reporting total precipitation in the 21- to 40-inch range. In the Southwest, as might be expected, total annual rainfall was the lowest for the nation. While a majority of that region's jurisdictions experienced 21 to 40 inches annually, half of them had totals in the 0- to 21-inch range. The Far West presented the widest variation in rainfall conditions, but the majority reported annual totals in the 0- to 20-inch range.

The survey brought to light a few notable exceptions where climatic and geological conditions provided unusually high rainfall, such as over 100 inches a year in Hawaii. Canadian jurisdictions reported annual precipitation in all the range categories used in the national evaluation. The number listed in the 0- to 20-inch range predominated. Despite local variations in national data, it can be said that the annual precipitation is relatively uniform for all regions. Obviously, some of the more arid Western states do not experience infiltration problems because the ground water table is extremely low. This was affirmed by the survey of state water pollution control agency practices and experiences.

Maximum monthly precipitation was reported to occur at various times of the year, primarily from April to September. Scattered cases of maximum precipitation during the winter and late fall months were disclosed in some areas, particularly along the west coast of the United States.

Another factor affecting infiltration rates, often overlooked, relates not only to the presence of water in the soil but also to the soil's nature and permeability. A tight soil actually might tend to seal sewer defects, even though a conduit is wet or immersed, if aquifer waters cannot flow readily through the voids of the soil and find entrance into the pipe system. Conversely, trenches for sewer lines in rock or hardpan clay, backfilled with porous material, act as conduits for ground or surface waters which penetrate the trench.

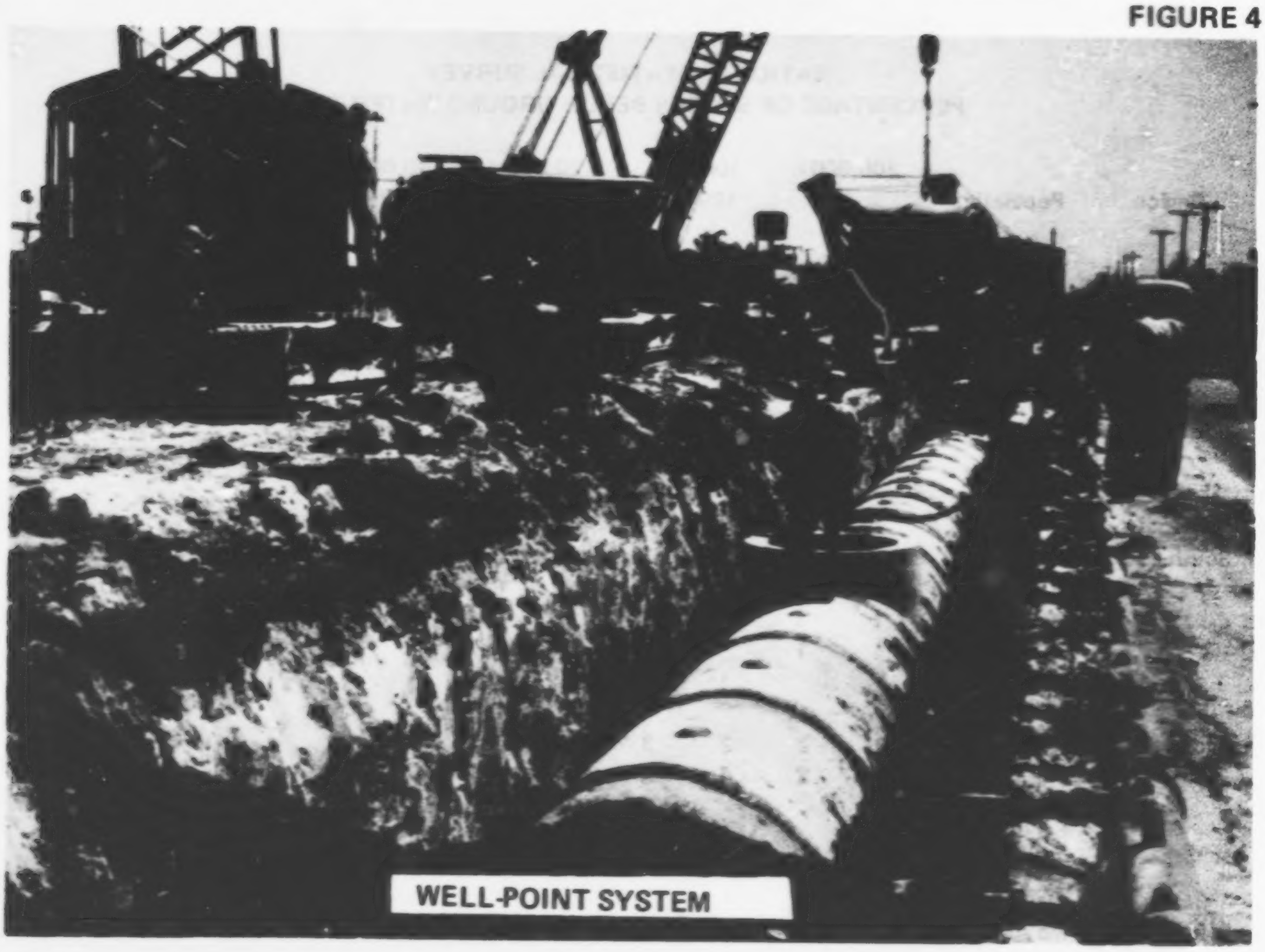
A review of the general classifications of soil conditions in the surveyed communities is contained in Table 20, National Statistical Survey – Soil Conditions at Sewer Locations. In all five regions in the United States and in Canada, clayey soil conditions predominated over sandy soil or rock formations. The Southwest was the only region reporting more rock than sandy soil. The results indicate it is difficult to assign specific soil conditions to any section of the country or even to any geological region. Jurisdictional officials, consulting engineers, and contractors must be prepared to make independent examinations and tests of soil conditions as the basis for design and construction of new sewers

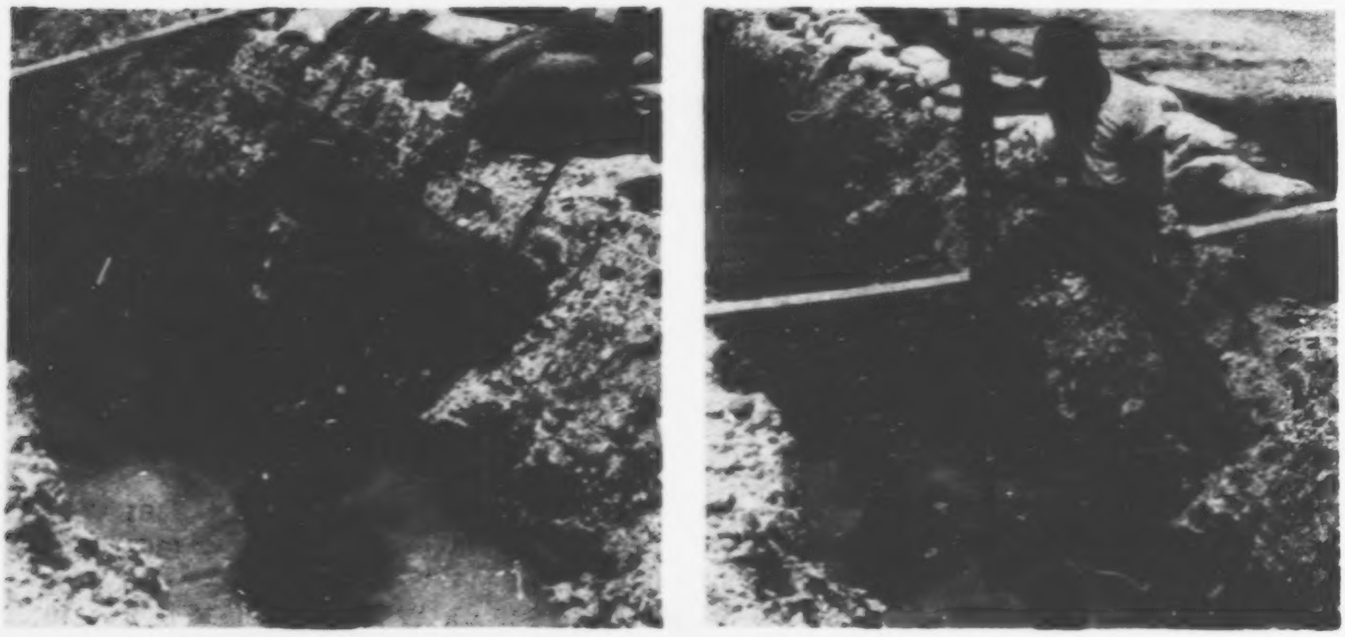
TABLE 18

NATIONAL STATISTICAL SURVEY
PERCENTAGE OF SEWERS BELOW GROUND WATER TABLE

Region	Population	200,000+		100,000-199,999		20,000-99,999		10,000-19,999		Under 10,000		Totals	
		Weather		Weather		Weather		Weather		Weather		Weather	
	Ranges	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
East	No Answer	6	6	3	3	16	17	3	4			28	30
	0- 25%	3	3	2	2	3	1	2	1			10	7
	26- 50%					4	3			1		5	3
	51- 75%			2	1						1	2	2
	76-100%				1		2						3
South	No Answer	3	4	3	3	3	3	3	3			12	13
	0- 25%	3	2	2	2	4	3	1				10	7
	26- 50%	1	1			1						2	1
	51- 75%	1	1			2	2					3	3
	76-100%			1	1		2		1			1	4
Midwest	No Answer	1	2	2	3	2	2	3	4			8	17
	0- 25%	2	2	4	2	12	9	4	3	1	1	23	17
	26- 50%				1	2	4					2	5
	51- 75%												
	76-100%	1					1	1		1	1	2	2
Southwest	No Answer	2	3	2	1	2	2		2			6	8
	0- 25%	4	3		1	7	6	2	2	1	1	14	13
	26- 50%		1			1						1	1
	51- 75%						1	1		1	1	2	2
	76-100%	1					1	1			1	2	1
West	No Answer	1	1	1	2	8	13	4	3	2	2	15	21
	0- 25%	6	4	4	3	19	10	6	6	1	1	36	24
	26- 50%		1	2	2	2	2	1				5	5
	51- 75%		1	1	1	1	1	1	1			3	4
	76-100%						4		1				5
Canada	No Answer	4	4	1	2	5	5		1	1	1	12	13
	0- 25%			1		5	5	2	1	1	1	9	7
	26- 50%								1				1
	51- 75%												
	76-100%							1				1	
Total	No Answer	17	19	12	14	36	42	13	17	3	3	81	95
	0- 25%	18	14	13	10	50	34	18	13	4	4	102	75
	26- 50%	1	3	2	3	10	9	1	1	1	–	15	16
	51- 75%	1	2	3	2	3	4	1	2	–	1	8	10
	76-100%	2	1	1	3	–	10	2	2	2	2	7	17

FIGURE 4





Courtesy: United States Concrete Pipe Co.

SEWER CONSTRUCTION UNDER WATER

TABLE 19

NATIONAL STATISTICAL SURVEY
ANNUAL RAINFALL AND MAXIMUM MONTHS

	Annual Rainfall (in.)		Max. Monthly Rainfall (in.)		When Max. Rainfall Occurs	
Region	Range	No. of Munici-palities	Range	No. of Munici-palities	Month	No. of Munici-palities
East	0- 20	–	0- 2	–	Jan.	1
					Feb.	–
	40	15	5	5	March	5
					April	3
	70	19	9	2	May	2
					June	–
	100	–	12	3	July	3
					August	3
	100 +	–	12 +	–	Sept.	2
					Oct.	–
	No Answer	11	No Answer	35	Nov.	–
					Dec.	–
South	0- 20	1	0- 2	–	Jan.	2
					Feb.	1
	40	4	5	3	March	4
					April	1
	70	18	9	6	May	1
					June	1
	100	4	12	2	July	5
					August	3
	100 +	–	12 +	3	Sept.	–
					Oct.	3
	No Answer	1	No Answer	14	Nov.	–
					Dec.	–
Midwest	0- 20	4	0- 2	–	Jan.	–
					Feb.	–
	40	22	5	4	March	1
					April	–
	70	1	9	10	May	1
					June	9
	100	–	12	3	July	–
					Aug.	–
	100	–	12 +	–	Sept.	–
					Oct.	1
	No Answer	8	No Answer	18	Nov.	–
					Dec.	–

TABLE 19 (Continued)

	Annual Rainfall (In.)		Max. Monthly Rainfall (In.)		When Max. Rainfall Occurs	
Region	Range	No. of Munici-palities	Range	No. of Munici-palities	Month	No. of Munici-palities
Southwest	0- 20	7	0- 2	–	Jan.	–
					Feb.	–
	40	15	5	5	March	–
					April	1
	70	2	9	5	May	3
					June	–
	100	–	12	1	July	–
					August	2
	100+	–	12+	1	Sept.	–
					Oct.	–
	No Answer	1	No Answer	13	Nov.	–
					Dec.	1
West	0- 20	38	0- 2	6	Jan.	13
					Feb.	3
	40	11	5	5	March	–
					April	–
	70	5	9	7	May	–
					June	3
	100	1	12	6	July	1
					August	–
	100+	1	12+	4	Sept.	–
					Oct.	1
	No Answer	3	No Answer	31	Nov.	–
					Dec.	4
Canada	0- 20	7	0- 2	1	Jan.	–
					Feb.	–
	40	7	5	2	March	–
					April	–
	70	2	9	3	May	1
					June	6
	100	1	12	–	July	1
					August	–
	100+	–	12+	–	Sept.	–
					Oct.	–
	No Answer	4	No Answer	15	Nov.	1
					Dec.	–

TABLE 20

NATIONAL STATISTICAL SURVEY
SOIL CONDITIONS AT SEWER LOCATIONS

Number of Agencies Reporting Each Soil Type

Region	Sandy	Clayey	Rock	No Answer
East	31	35	19	7
South	14	20	6	1
Midwest	22	30	10	0
Southwest	12	22	16	0
West	41	46	23	3
Canada	10	15	5	0
Total	130	168	79	11

and in determining correctives for infiltration into old sewer lines.

Importance of Infiltration Control in Existing Systems

The national study endeavored to ascertain the views of officials as to the importance of the infiltration problem in existing systems. The thinking behind this phase of the survey was that infiltration conditions will not be detected or corrected unless local and state officials are aware of either the problem's existence or the way it is affecting the capacities of sewers, pumping stations, treatment plants, combined sewer overflow facilities, and water pollution conditions.

To provide this pulse-taking information from local and state officials and consulting engineers, many inquiries were made concerning the importance, causes, and effects of infiltration. Officials were asked whether they considered infiltration very important, of average importance, or of minimum importance. The significance of this line of questioning readily is understandable because the responses would signify to what degree these officials desire to take corrective action.

Table 21, National Statistical Survey – Opinions of Local Officials On Importance of Infiltration Problem, summarizes the views expressed.

It shows that 109 municipalities regarded infiltration as very important; 55 jurisdictions regarded it as having average importance, and 22, minimum importance. Among population groupings, the 200,000-and-over group totaled the highest percentage of responses in the minimum importance classification, although the responses in the very important classification exceeded these by better than 3 to 1. However, in all other population categories this ratio was 5 to 1 or greater. A similar regional comparison between "very important" to "minimum importance" revealed that the East, West, and Southwest were all close to a 5 to 1 ratio while the South and Midwest showed 13 to 1 and 16 to 1, respectively. Surprisingly, seven jurisdictions in Canada classed infiltration as very important while five gave it minimum importance.

These statistics reveal that although infiltration control's high level of importance generally is recognized throughout the United States and Canada, there are variations within regions and population groups. It might be expected that the high population cities would express less concern over the infiltration problem, since many of their systems still use combined sewers where infiltration during high intensity rainfall is less of a factor in the total sewer-flow increase. The East's slightly lower level of interest may be attributable to the use of combined sewers. Despite the impact of infiltration on these systems, the effects are less serious than in separate sanitary sewers which have lesser capacities and no provisions for storm overflows.

In addition to municipalities, all the states and provinces were asked similar questions. Infiltration was reported to be a problem of importance in 48 states and five provinces.

Also indicating the importance was the response of more than 70 percent of the consulting engineering firms participating in the survey covering their experiences and practices. Retention of consulting firms to carry out infiltration surveys was reported by approximately two-thirds of the respondents. Almost as many of the firms reported they also were retained to design and supervise actions to correct excessive infiltration. This is a clear indication that jurisdictions now consider control of infiltration as a necessary action in sewerage system maintenance and operation.

Sources of Excessive Infiltration in Existing Systems

Modern methods of locating and correcting infiltration sources offer sewer officials opportunities that previously were unavailable. They provide the added benefit of economy of investigation and ease of corrective actions.

In recent years, closed circuit TV inspections and still photographic inspections have come into common usage in many parts of the country. Where

TABLE 21

NATIONAL STATISTICAL SURVEY
OPINION OF LOCAL OFFICIALS

Population	200,000+				100,000- 199,999				20,000- 99,999			
	Importance				Importance				Importance			
Region	Very	Av.	Min.	N.A.	Very	Av.	Min.	N.A.	Very	Av.	Min.	N.A.
East	4	3	1	1	5	2	–	–	13	4	3	3
South	7	1	–	–	6	–	–	–	4	5	1	–
Midwest	1	2	1	–	3	3	–	–	11	4	1	–
Southwest	3	2	2	–	1	1	–	–	6	2	1	1
West	3	3	1	–	4	2	2	–	19	6	4	1
Canada	2	–	2	–	–	1	1	–	4	4	2	–
Totals	20	11	7	1	19	9	3	–	57	25	12	5

Population	10,000- 19,999				Under 10,000				Totals			
	Importance				Importance				Importance			
Region	Very	Av.	Min.	N.A.	Very	Av.	Min.	N.A.	Very	Av.	Min.	N.A.
East	3	2	–	–	1	–	–	–	26	11	4	4
South	2	3	–	–	–	–	–	–	19	8	1	–
Midwest	3	3	1	–	–	2	–	–	18	14	3	–
Southwest	2	1	–	1	–	1	–	1	12	7	3	3
West	6	3	1	1	3	–	–	–	35	14	8	2
Canada	1	–	2	–	2	–	–	–	9	5	7	–
Totals	17	11	4	2	6	3	–	1	119	59	26	9

TV systems are employed, they sometimes are used as a routine initial method for locating points of damage and infiltration in both new and old sewer lines.

Previous sections of this report have delineated some of the sources of infiltration prevailing throughout the United States and Canada. Some of those reported include:

1. Infiltration through sewer joints;
2. Infiltration through sewer cracks;
3. Infiltration into manholes;
4. Infiltration through building sewers and joints; and
5. Infiltration through connections of building sewers with street sewers.

Thus, there are three basic sources of infiltration: (1) Street sewers, (2) building sewers, and (3) manholes and appurtenant chambers.

The mere presence of defective sewer structures, however, does not presuppose that infiltration water will penetrate into these lines. The second ingredient of infiltration is *water.* There must be water, plus points of entry, for infiltration to occur.

The national statistical survey explored the sources of infiltration in respondent jurisdictions, and attempted to affix specific percentage estimates of the total sewer-system infiltration attributable to these sources. The data were collated in the following categories: 0-15 percent, 16-30 percent, 31-45 percent, 46-60 percent, 61-75 percent, 76-90 percent, and 91-100 percent. Opinions on sources of infiltration and their percentage importance in relation to the total extraneous water volumes in sewer systems are summarized in Table 22, National Statistical Survey – Reported Sources of Excessive Infiltration.

The tabulation data demonstrate that the most prominent source of infiltration, listed by the greatest number of jurisdictions, is through defective joints.

TABLE 22

NATIONAL STATISTICAL SURVEY
REPORTED SOURCES OF EXCESSIVE INFILTRATION

Population				200,000+			
Sources	0-15%	16-30%	31-45%	46-60%	61-75%	76-90%	91-100%
Through Joints	7	5	2	1	4	1	
Through Cracks	19	1					
Into Manholes	14	2					
				100,000-199,999			
Through Joints	8	2	1	5		2	
Through Cracks	14	5					
Into Manholes	15	3	1	1			
				20,000-99,999			
Through Joints	20	14	12	10	2	3	1
Through Cracks	39	13	4	1			
Into Manholes	45	5	3	1			
				10,000-19,999			
Through Joints	8	2	2	3		3	
Through Cracks	13	4					
Into Manholes	12	3					
				Under 10,000			
Through Joints	1	1	2			2	
Through Cracks	5	1					
Into Manholes	5	1					
				Total			
Through Joints	44	24	19	19	6	11	1
Through Cracks	90	24	4	1			
Into Manholes	91	14	4	2			

The officials gave varying estimates of the relative importance the entry of extraneous water via this type of defect. No other source of infiltration was cited as consistently; it was reported in all areas of the United States and in Canada.

Defective sewer barrels and defective manholes also were listed as sources of excessive infiltration, but in general they were classified as of relatively lesser significance – in the 0-15 percent category. In the case of infiltration through joints, a number of jurisdictions, particularly in the 20,000 to 99,999 population category, attributed to this source as much as 61 to 75 percent of the total ground water entry into sewerage systems.

It should be pointed out that this inquiry covered not only infiltration conditions but the sources of inflow into sewer systems and the relative importance of these inflow points. This information on inflow is summarized and evaluated in Section 5 of this report.

Causes of Excessive Infiltration In Existing Systems

The survey of state and provincial water pollution control agencies explored the agencies' opinions on infiltration sources in their regions. Poor joints in old sewer systems were the most frequently listed source. This condition was reported by 24 states. Paralleling it were such reported causes as poor construction, poor inspection, poor maintenance, and shifting of old sewer lines due to poor soil conditions and unsatisfactory backfill methods.

In the United States other causes of infiltration were listed as usage of low strength pipe, poorly installed building sewers, illicit connections, and high ground water tables. High ground water table conditions were listed by eight states as the cause of infiltration.

In Canada, poor joints, illicit house connections, poor house sewer caps, and poor construction were listed as causes. Poor joints and high ground water tables were so listed in three provinces.

Effects of Excessive Infiltration In Existing Systems

In the data resulting from the survey of state and provincial water pollution control officials, it was revealed that infiltration causes the overload of waste water treatment plants in 50 percent of the states and provinces. The next most widespread effect was reported to be overloaded sewers and local basement flooding. By-passing of flows to allay surcharged sewers, local flooding, and plant overloading were reported by 13 states. Increased cost of treatment was reported by five states, and interference with treatment efficiency by three. Other effects were reported as damaged sewers, increased pollution conditions in receiving waters, and shortened design life of sewage works facilities.

In Canada, overloaded sewage treatment plants and surcharged sewers were the predominant effects of infiltration, in the opinion of provincial water pollution control agencies. Other adverse conditions were listed as early obsolescence of facilities, upsetting of lagoon treatment systems, and excessive overflows to streams.

The national municipal statistical survey revealed that infiltration caused sewer surcharges and local flooding, overloading of sewage pumping stations, excessive overflows of combined sewers, and treatment plant overloading and by-passing. Treatment process problems reportedly have resulted from excessive flows of storm water. In the over-200,000 population category, the greatest effect of infiltration was reported to be sewer surcharging and local flooding. In the 100,000-to-199,999 range, it was pumping station overflows. In the 20,000-to-99,999 range it was waste water treatment plant overloading. In the 10,000-to-19,999 group, reports of overloading and treatment plant operation problems predominated. In the under 10,000 range, combined sewer overflows were most frequently cited.

Overall, sewer surcharging and flooding led the list of reported difficulties, with more than 50 percent of the problems attributable to this condition. Pumping station overloads were almost equally prevalent – again, with 50 percent of the jurisdictions reporting this condition. Waste water treatment plant problems, due both to overtaxing of capacities and adverse process effects, were reported in 58 of the 66 replies from respondent jurisdictions – or almost 90 percent of the total participants in this phase of the national survey.

Benefits of Correction Of Existing Infiltration

The predominating benefit cited by consulting engineers was the reduction in wastewater treatmentplant costs. In 10 cases, this was reported as the most tangible and measureable benefit of infiltration control. Improved operation of plant units and sludge digestion facilities were cited. Postponement of plant enlargement was attributed to infiltration control in the case of one jurisdiction. Elimination of sewer surcharge and basement flooding and property damage frequently were reported. Regained sewer capacity after infiltration control was reported by six respondent consulting firms.

Other benefits cited by these firms included elimination of salt water intrusion into sewerage systems, reduced sewer maintenance costs, and correction of harbor pollution through control of combined sewer overflows or sewer system by-passing.

One consultant said corrections were not instituted because of "political complications." Three noted that in some jurisdictions corrections were too costly for the benefits derived. But it is significant that in most cases consulting engineers said benefits were sufficient to compensate for the cost of infiltration control. Ten times as many reported positive economic benefits as reported costs outweighing the benefits.

Officials of jurisdictions in the national statistical survey were asked to express their views on the potential benefits of infiltration control measures. Specifically they were asked about lower pumping costs, improved treatment plant operation, reduced stream pollution, reduced system repairs, reduced sewer surcharging and flooding conditions, elimination of immediate need for new sewer construction, and miscellaneous benefits. In all regions of the United States, and in all population size ranges, officials were of the opinion that control measures could achieve one or more of the listed benefits. However, the affirmative evaluations were distinctly lower in the communities below 10,000 population.

In Canada, the only population group expressing affirmative views on all the tabulated benefits was in the 20,000- to 99,999- population range. In the other size groupings, little benefit was seen as resulting in any of the categories except lower pumping requirements and improved treatment plant operation.

A similar proportion of affirmative reactions was shown in the under-10,000 population grouping of the United States in the East, South, Southwest, and West. The Midwest differed from the other areas in this respect; opinions were affirmative on all the listed potential benefits.

The greatest number of affirmative responses was in the 20,000-to-99,999 population grouping, just as it was for the survey of the relative importance of infiltration control.

This phase of the national municipal statistical survey indicated that sewer system officials believe specific benefits can be derived from infiltration control measures.

Methods of Detection of Existing Infiltration Sources

Several techniques were reported by surveyed jurisdictions for use in locating sources of infiltration in existing sewer systems:

Infiltration flow measurement with weirs, flumes, or other flow measuring devices usually are made at off-peak hours and during dry and wet-weather conditions to determine the variations attributable to infiltration. In an old system, inflow may account for part of this excess flow and it cannot be distinguished from infiltration. However, if excessive flows do not appreciably increase immediately after rainfall and runoff, they can be considered infiltration. If the flow increases markedly within an hour or so after the beginning of an intense rain, inflow from roof leaders, drains, and sump pumps can be suspected.

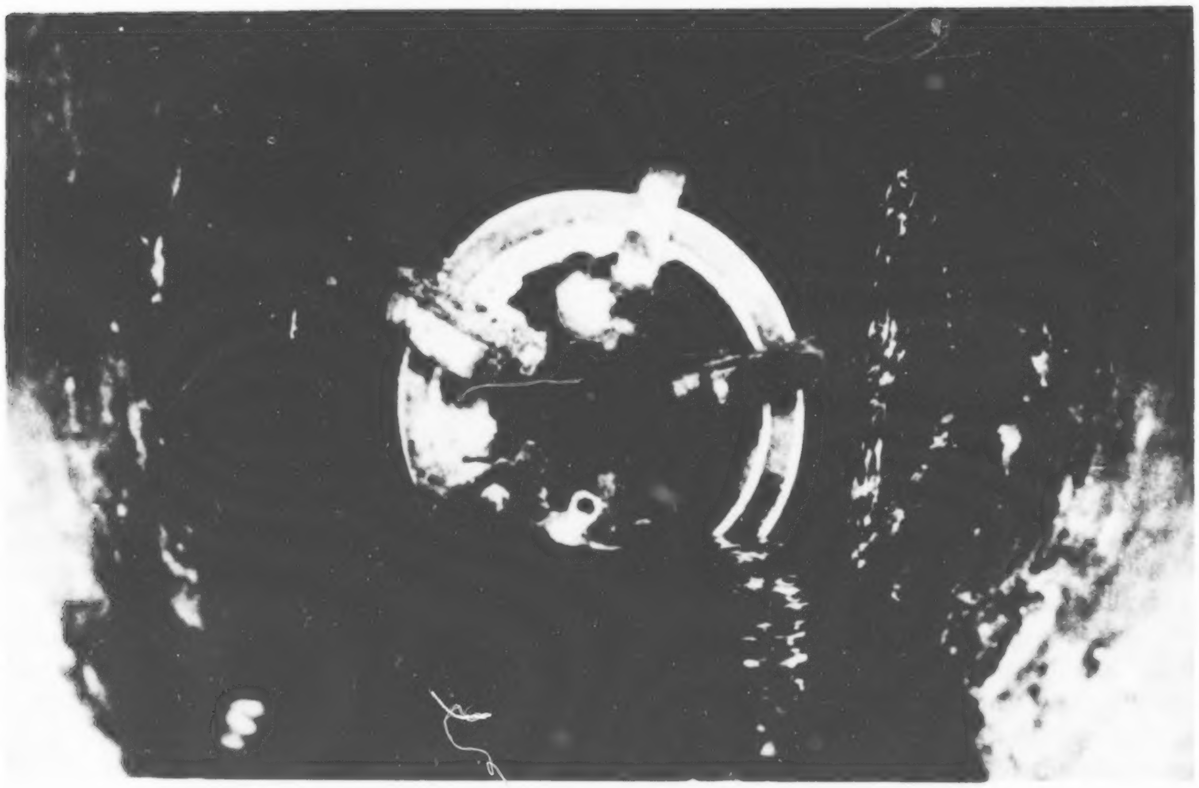
For many investigations actual flow may not need to be measured. Instead correlations are developed as to inches of flow during dry weather, wet weather and rainfall simulations. Depth of flow within the sewer may be more economical to determine, and if needed can be corrected to flow by appropriate calculations.

Ground water level measuring devices in manholes – in the form of a tube inserted through the manhole wall, with a gage utilizing a clear plastic tube placed along the manhole wall (head checkers) – can assist in evaluating the extent of sewer immersion in ground water.

Smoke Testing can at times indicate poor joints and cracked pipe by showing up on the ground surface near the leak. If the ground water table is above the pipe, the smoke may be lost in the water. Smoke can also indicate illicit connections by appearing inside, outside, or at the roof line of a house or other structure or in cross connected facilities.

Television Inspection, with a closed circuit camera pulled through the suspected pipe, can disclose defective sections and actual infiltration flows when a high ground water condition exists. Amounts of infiltration can be roughly approximated and the condition can be recorded by video tape or Polaroid cameras. TV systems are constantly being refined to reduce the size of equipment, increase the clarity, color and depth of

FIGURE 6



Courtesy: Penetryn System, Inc.

INFILTRATION AT OFFSET JOINT

image, and reduce operating costs.

Some advantages of TV inspection include immediacy of observation, ability to detect movement of waters, ability to observe changes in flow, and the advantage of moving back to recheck or watch repair operations.

Photographic Inspection methods are being used to permit taking photographs of sewer interiors. Although photography is applicable to inspection of new construction, it also can be used to obtain clear and interpretable pictures of existing defective sewers. For permanent records it is economical and convenient, but it cannot provide the intimate and immediate knowledge that TV inspections afford. A combination of the two techniques may be feasible.

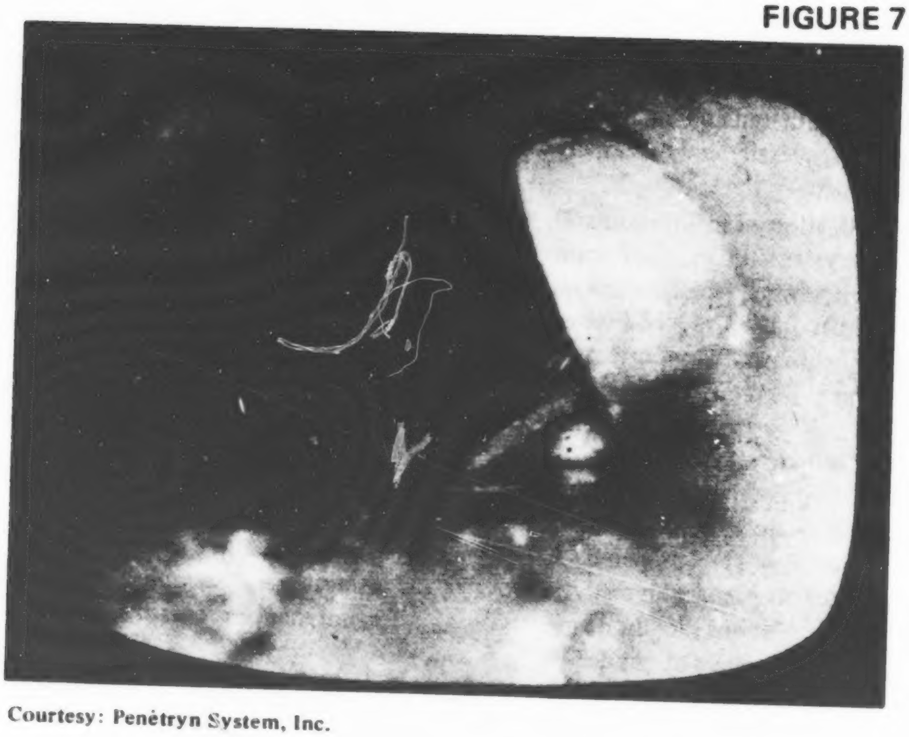
Figure 6 Infiltration at Offset Joint, is a photograph of infiltration occurring at a defective joint. Sealing equipment is shown behind the joint, waiting to be used. Figure 7, Improperly Installed Sewer Connection, is a photograph of an 8-inch sewer. The building sewer intruding into the sewer may leak and will impede cleaning. Figure 8, Broken Joint, is a photograph of a broken joint on a 12-inch pipe. Although not leaking at the time of inspection, infiltration can be expected.

- **Bottle Gauges** and more sophisticated devices are used to indicate the degree of surcharging in a manhole. Such devices either float and indicate the highest water level attained in the manhole or they collect samples at various points to show the peak level experienced in the chamber. New developments in telemetering and stop-action photography also can be used to photograph or transmit sewage level measurements behind weirs, to augment liquid level registration-recording data.
- **Rainfall Simulation Tests** sometimes are used to detect cross-connections and leaks between storm and sanitary sewers by flooding adjacent storm sewer sections and checking for the appearance of dyed water in a sanitary system.

Comprehensive Planning for Infiltration and Inflow Control

Prior to the design of sewer system extensions or wastewater treatment plant facilities, comprehensive

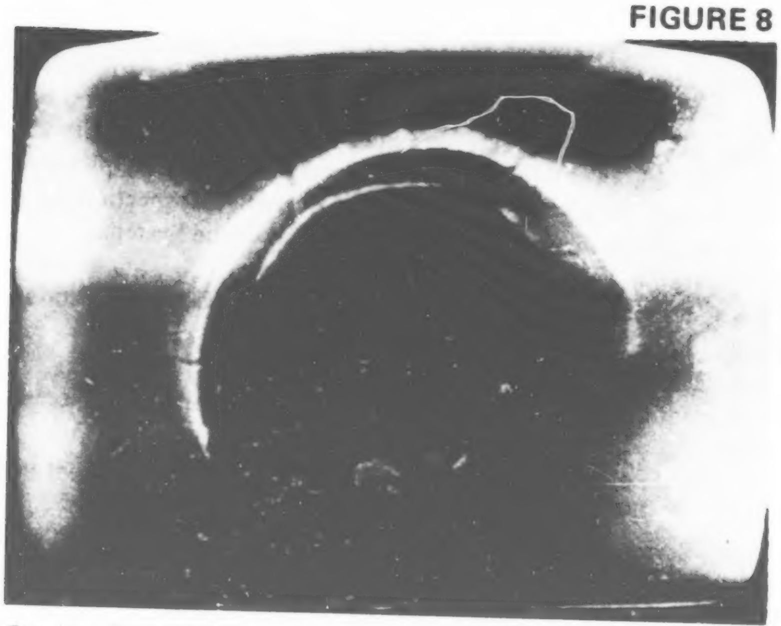
FIGURE 7



Courtesy: Penetryn System, Inc.

IMPROPERLY INSTALLED SEWER CONNECTION

FIGURE 8



Courtesy: Penetryn System, Inc.

BROKEN JOINT

planning is needed to ensure that an economical facility will be constructed. The planning stage may require two years to complete in order that all pertinent information may be gathered and analyzed. The cost of this planning is generally only a small portion of the construction cost.

A comprehensive investigation of infiltration and inflow will involve ground water studies, roof drain checks, flooding of storm sewers, sewer surveys, analysis of flow charts and lift station records, sewer cleaning and inspection, followed by intensive interpretation and evaluation.

Funds for Comprehensive Planning

The cost of the type of comprehensive planning described was not contemplated when existing consulting engineer fee schedules were prepared. A consultant cannot be expected to prepare an analysis of infiltration and inflow conditions at the same percentage rate as would be charged under a "reasonable curve" as typified by the ASCE C schedule. An additional difficulty at this time is that construction grants from most federal and state agencies do not consider such comprehensive planning eligible for inclusion in the allowable costs. The Federal Water Quality Administration does not have planning money available. The Federal Housing Administration has limited planning money but it has not been made sufficiently available for studies of infiltration and inflow control. The Department of Housing and Urban Development does not have a clear mechanism for including planning funds in a construction grant request. This lack of funds for planning is a paradox as both the local agency and the grant awarding agency could benefit from reduced construction costs if infiltration and inflow conditions were remedied. Local agencies who receive construction grants are usually those which are not able to adequately fund such planning on their own and thus only a minumum of planning is performed prior to design of such facilities.

A Suggested Plan of Action

The Sub-Committee on Sewer Service and Maintenance of the Industrial Advisory Panel, created by APWA as a part of its investigation provided important information for evaluation by the project staff. Taking up the question of infiltration surveys, evaluation of the extent of infiltration, and methods of restoring sewer lines to infiltration-free condition, a memorandum was prepared by one of the engineering support organizations represented on this subcommittee. A brief outline of a 10-stage program for analysis and restoration of sewer systems is included as a portion of this report because it demonstrates the logical step-by-step procedures which may be of service to municipalities for the location and correction of excessive infiltration. (A more complete exposition on a multi-phase pre-cleaning-survey-evaluation-correction program of infiltration control is contained in the Manual of Practice.)

A TEN-STAGE PROGRAM FOR INFILTRATION ANALYSIS AND THE RESTORATION OF SEWER SYSTEMS

Stage One – Set Objectives.

- A. The first problem is to find the problem.
- B. Determine the need for a sewer system analysis and establish a systematic sewer maintenance program.

Stage Two – Develop a Workable Plot Plan of the Sanitary and Storm Sewer Systems.

Stage Three – Identify the Scope of the Infiltration:

- A. Place ground water level gauges in manholes.
- B. Install recording devices at lift stations in metering stations.
- C. Survey the presence and extent of inflow.

Stage Four – Make a Rainfall Simulation Study.

Stage Five – Determine the Extent of Pre-cleaning Needed to Produce Optimum Results from TV or Photographic Inspection in the Isolated Trouble Sections of the System.

Stage Six – Make an Economic and Feasibility Study.

Stage Seven – Carry Our Necessary Initial Cleaning.

Stage Eight – Make Television Inspections.

Stage Nine – Restore and Repair System.

- A. Structural deficiencies.
- B. Infiltration.

Stage Ten – Establsih Treatment Plant Design Criteria.

The foregoing procedure outlines an extensive and logically oriented program for the determination and correction of infiltration and inflow conditions.

Plans for Future Corrective Action

The national statistical survey attempted to ascertain whether or not representative jurisdictions in the United States and Canada intend to carry out precorrective surveys of infiltration conditions in their sewer systems; whether such surveys will be followed by actual corrective actions, where needed or indicated; and whether budgetary funds have been or will be allocated for such work. The survey data obtained in response to these inquiries are contained in Table 23, National Municipal Statistical Survey – Future Corrective Action in Infiltration Control.

The survey information indicated that more jurisdictions than not are planning to carry out infiltration surveys. A number could give no clear information on this question because of budgetary and administration problems.

The large number of communities not contemplating such surveys can be attributed either to their not giving this matter sufficient thought and attention, the absence of problems severe enough to warrant any such survey efforts, or possibly not knowing where to begin analyzing the problem. In the Southwest this large percentage may indicate such work is unnecessary because of low precipitation, low ground water tables and, consequently, the limited amount of infiltration experienced in this relatively dry region.

Although a great many of the responding jurisdictions did not plan infiltration surveys, a large percentage reported actual plans for corrective actions. Thus, in spite of the lack of full-scale infiltration surveys, most communities realize there are places within their systems that require correction, and they are planning programs to reduce or eliminate such excessive flows. A further discussion of the costs and economic factors involved in infiltration and its control will be found in Section 8 of this report.

Method of Correction of Existing Sewer Infiltration

After the economic and practical feasibility of correcting sewer infiltration has been determined, there are three basic approaches: (1) replace the defective component, (2) seal the existing openings, and (3) build within the existing component.

Replacing sections of sewers found to be damaged is, at times, the only alternative. However, it may be the most expensive method of correction and the most disruptive to the local environment and public convenience. For this reason, if the problem appears to be one of open joints or pipe cracks and the pipe itself is structurally sound, there are alternative methods of repair without excavating and replacing the sewer line. If the sewer pipes are of a large diameter, such as in large interceptor trunk systems, they may be sealed either by machine lining or manual lining of joints. Figure 9, Manually Lined Joints, is a photograph of steel banded joints to reduce infiltration.

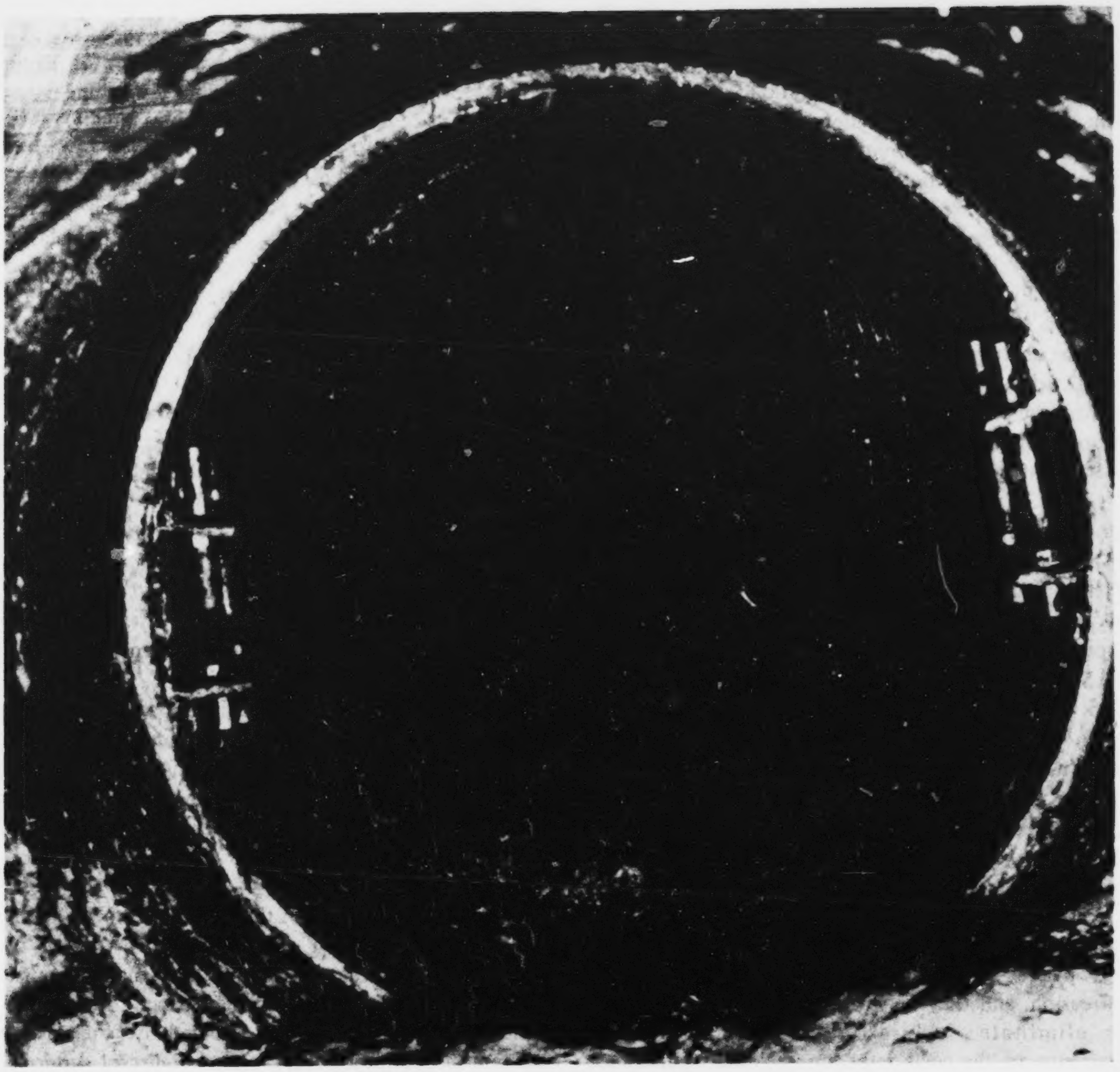
Large diameter pipes, even when theyre structurally damaged, may be repaired by plastic liners within the pipes. This has been accomplished with reported success in Toronto, Canada, where the Commissioner of Public Works has developed a special technique for installing plastic liners. Recently developed reinforced plastic mortar pipes also have been utilized in some sections of the country for lining large diameter sewer lines. Figure 10, Installation of Pipe Liner, shows a fiberglass pipe liner being inserted into a deteriorated pipe. The smooth inside surface of the liner may allow the same flow to be carried as in the larger original pipe.

House sewers may be repaired by replacement since these may be too small for use of internal grouting techniques. However, external chemical grouting has been used for this purpose.

A common method of sealing leaks involves the introduction of chemical compounds which, in contact with the soils surrounding the defective points in sewer lines, from a "cast" or "bandage" around the pipe. This method of sealing has produced some excellent results when used for application under pressure from inside of sewer lines, whence it extrudes to the outside of the pipe and into the pores of the surrounding soil. The introduction of congealing chemical gels also has been made into the soil by direct injection from the surfact at the points where infiltration has been detected by a television camera inspection or other means. Figure 11, Internal Grouting Equipment, shows equipment in place for the purpose of sealing a joint. The first photograph shows the "train" of the TV equipment and the packer in a deflated position. The television camera is used to align the position of packer and to check the condition of the joint after sealing. The second photograph shows the packer in an inflated position ready for sealing. The packer is hollow, generally allowing wastes in existing sewers to continue to flow without disruption.

The Federal Water Quality Administration, U.S. Department of the Interior, has issued a report on "Improved Sealants for Infiltration Control." It covers the development and demonstration of materials to reduce or eliminate water infiltration

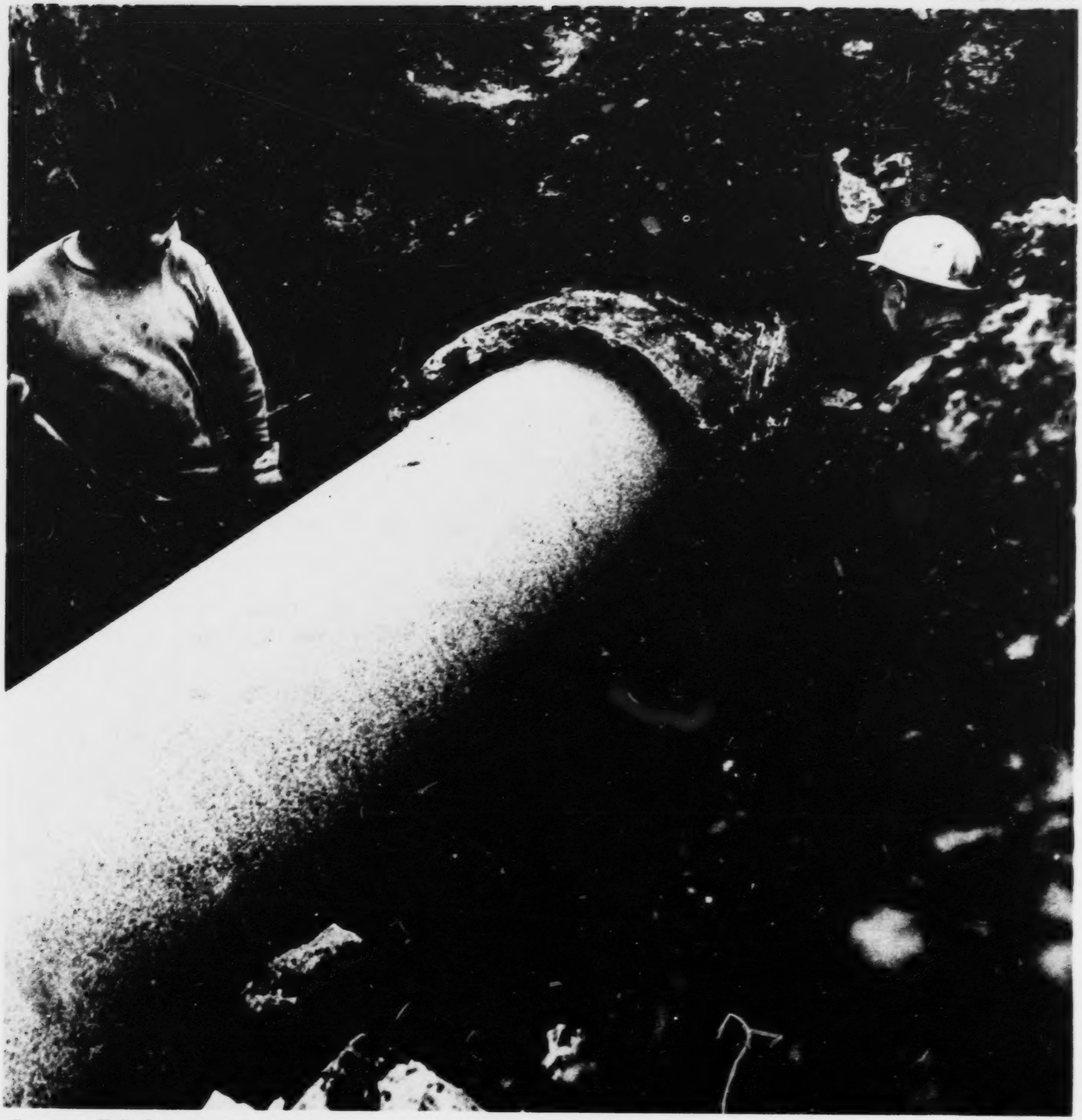
FIGURE 9



Courtesy: Armco Steel Company

MANUALLY LINED JOINTS

FIGURE 10



Courtesy: United Technology Center

INSTALLATION OF PIPE LINER

into sewer systems. The objective of this research program was to develop new and more effective sealants for sewer line leaks, investigate all equipment and materials required for such work, and test and compare various materials on the basis of effectiveness and economy. The study illustrates current interest in infiltration control and the need for continuing research and development of effective grouting or sealing materials to repair defective conduits and joints.

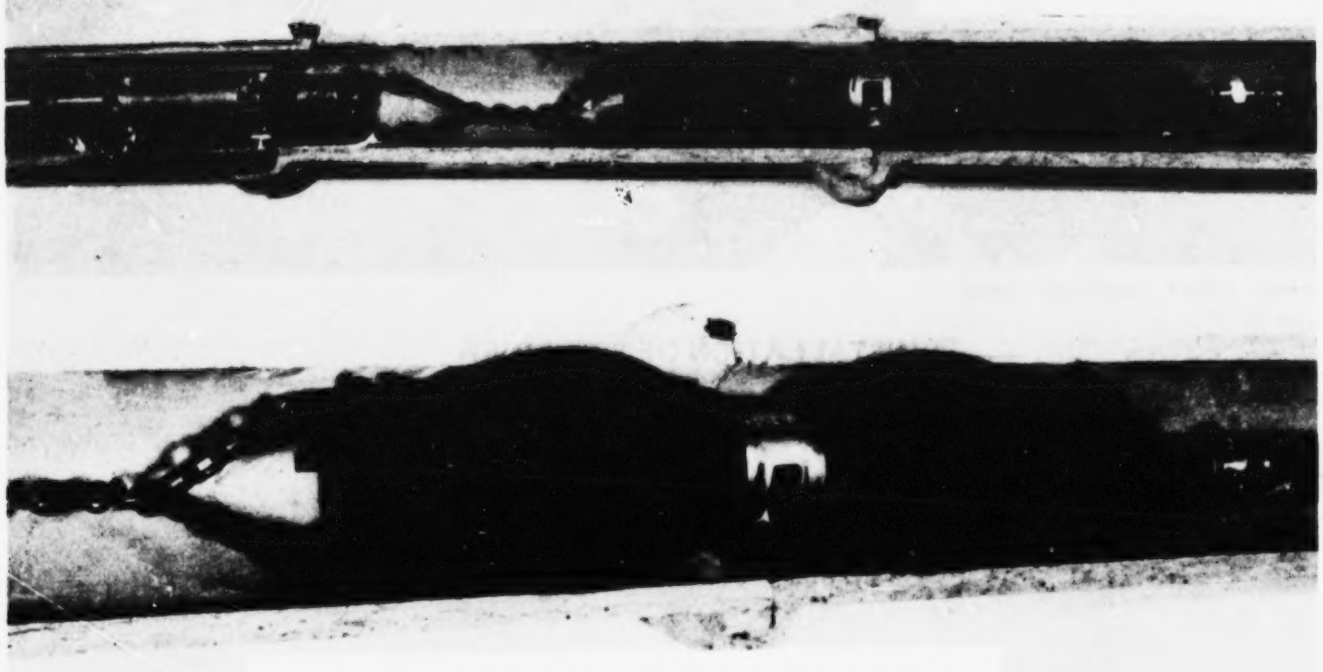
The major emphasis of this section has been on infiltration. Methods for inflow analysis are discussed more fully in Section 5 of this report.

TABLE 23
NATIONAL STATISTICAL SURVEY
FUTURE CORRECTIVE ACTION ON INFILTRATION CONTROL

POPULATION	200,000			100,000-199,999			20,000-99,999		
	Yes	No	NA	Yes	No	NA	Yes	No	NA
Will city conduct Infiltration Survey	21	14	4	14	12	5	43	34	22
Will defective sewers be sealed or replaced	32	2	5	24	3	4	75	8	16

POPULATION	10,000-19,999			Under 10,000			Totals		
	Yes	No	NA	Yes	No	NA	Yes	No	NA
will city conduct Infiltration Survey	2	10	12	4	5	1	94	75	44
Will defective sewers be sealed or replaced	22	4	8	5	1	4	141	18	37

FIGURE 11



INTERNAL GROUTING EQUIPMENT

SECTION 5

THE INFLOW PROBLEM

This project was planned and executed to distinguish between *infiltration* water and *inflow* water, in order to evaluate these dual causes of extraneous water flows in sewer systems, their effects, and means of correction. True, infiltration and inflow have the same general effect of impairing the ability of sewer systems, combined sewer regulator-overflow facilities, pumping stations and treatment plants, to render the service for which they were designed, constructed and operated. However, their specific causes may be different, and the means of correction are entirely different.

It obviously is desirable, therefore, to consider these two components of extraneous entry waters separately, wherever this is possible, and examine them as two separate problems. This has been done for this research study. (The problem of infiltration has been covered in Section 4 of this report.)

The distinction between the "Two I's" was delineated in Section 2 of this report. To clarify the following discussion of the *inflow* problem and the data obtained on national practices, policies, and performance during the course of the investigations, the definition of inflow is again stated:

> "Inflow covers the volume of any kind of water discharged into sewer lines from such sources as roof leaders; cellar and yard area drains; foundation drains; commercial and industrial so-called clean water discharges; drains from springs and swampy areas; etc. It does not include, and is distinguished from infiltration as previously defined." (As covered in Section 4 of this report.)

Sources of Inflow

The definition spells out the basic sources of inflow into sewer systems. Such sources of inflow generally are related to private buildings and private land areas. They usually represent a deliberate connection of a drain line to a public sewer system.

These connections may be authorized and permitted; or they may be illicit connections made for the convenience of property owners and for the solution of on-property problems, without consideration of their effects on public sewer systems.

If permitted by sewer, plumbing, or housing codes, these connections are deliberately made and the discharges to the sewer system are, at least in theory, provided for in sewer design. Obviously, in many instances, the removal of such extraneous water from properties and buildings is essential for protection of the living environment and preservation of the value of the properties involved. However, the trend is toward permitting such connections to storm sewer or combined sewer systems, rather than to building sewer lines discharging into separate sanitary sewers.

Even this generalization is not justified under all circumstances. Some sewer authorities favor the connection of cellar or sump drains to sanitary sewers, on the basis that the waste water originating in such drain lines will contain laundry wastes, basement wash water, and other liquids which, appropriately, should be carried by sanitary sewers. Roof leaders fall into a different category. Despite the fact that such drainage water often contains particulate wastes stemming from atmospheric pollution sources, bird droppings, rodent wastes, and other debris, many authorities advocate the discharge of roof water into street gutter areas – or onto on-lot areas in the hope that it will seep into the soil by percolation.

Building sewer connections may carry such extraneous inflow waters, and infiltration waters too, where the lines are poorly constructed or have become defective during years of service. However, the inflow factor must not be confused with the infiltration problem in building sewers, as briefly discussed in Section 4 and more fully evaluated in Section 7.

Industrial-Commercial "Clean Waters"

The problem of inflow volumes having their sources in commercial and industrial operations is separate and apart from the roof leader and basement and foundation drain lines. Of course, commercial and industrial buildings have similar drain connection problems, and the roof drainage volumes discharged from large flat and semi-flat roof surfaces of large structures are even more extensive than from homes and other smaller buildings. But the inflow problem to which this discussion refers is the result of actual in-structure operations. The inflows from these sources include so-called clean waters from on-stream operations, cooling waters, and other related functions. They can represent relatively large volumes of water that could seriously affect the carrying capacity of sanitary sewers, if such connections are made in accordance with local rules or ordinances, or in violation of regulations prohibiting such discharges.

It is difficult to rationalize hard and firm reasons for permitting or prohibiting such inflows into sewer systems. If such waste waters are deemed pollutional in nature, there may be justification for authorizing their discharge into sanitary or combined sewer lines. If, however, they are of the "clean" nature indicated in this project's definition of inflow waters, discharge into sanitary and even combined sewers may be highly undesirable. Disposal of such waste waters may be necessary to the proper and effective use of commercial-industrial properties and essential to on-stream operations in such installations; in such cases their discharge into storm sewers or combined sewers may be required.

It may be reasoned that a municipal jurisdiction must provide for some form of legitimate collection and transportation of such unavoidable waste waters. This is why the principle of re-use of on-stream waters is attracting wide attention. Reclamation and re-use of such waters as clean cooling waters can greatly reduce (1) the volumes of inflow waters which must be carried by public sewers and (2) the water supply demands. It is obvious that designers and operators of sewer facilities should explore this trend.

Nature of Inflow Waters

It is necessary to draw a quality comparison between infiltration waters and inflow waters. The former liquids, in the main, have not been directly exposed to man-made environmental conditions; essentially, their source is ground water resulting from precipitation conditions. In the absence of ground water juxtaposed to sewer conduits, infiltration is not a problem. Inflow waters, as outlined above, have been more directly exposed to the environment and carry environment-induced or man-produced contaminants.

To some extent, this variance in sources results in some differences in quality of the "Two I's," but the two types of extraneous water which intrude into sewers do not differ significantly in quality, except for the pollutants unavoidably or deliberately introduced into inflow waters by commercial-industrial operations. Foundation inflow, for example, does not vary greatly from the kind of water which infiltrates sewer lines from ground water sources. Basement drainage may carry wastes and debris originating in homes, including laundry waste water.

Effects of Inflow

"Volume" is the most important characteristic of inflow waters, just as it is of infiltration waters. While the former waters contain suspended and dissolved pollutional constituents, and while infiltration carries sand and silt entering sewer systems with the ground water, these are not usually predominating factors in the operation and performance of sewer systems and pumping and treatment facilities. The amount of inflow waters which rob sewers and sewage-handling installations of essential capacities produce the same kind of effects as excessive volumes of infiltration.

Some minor differences in the effects of the "Two I's" are worthy of note. Inflows do not cause the clogging of sewers with sand, gravel, and other soil debris entering sewers with infiltration water. Inflows do not induce the growth of tree roots that intrude into sewer barrels through the same defective joints and pipe cracks and breaks that permit the infiltration of ground water.

Except for these variations between inflow and infiltration effects, the conditions outlined in Section 2 prevail for both extraneous water phenomena. The effects of excessive inflow waters include:

- Flooding of local sewer lines, streets, and roadways.
- Backflooding of connected properties.
- Increased cost of pumping and sewage treatment.
- Reduced life of pumping and treatment units.
- Reduced capacity of sewers to handle added urban developments, foreshortening the life of sewer systems, and adding to the need for auxiliary sewer construction.
- By-passing of pumping stations and treatment processes to prevent overloading and malfunctions.
- Excessive overflows from combined sewer systems at regulator stations.
- Need for diversion of flows from sanitary sewers to adjacent storm sewers or nearby watercourses, to overcome serious surcharging of lines receiving excessive inflow waters.

Correction of Excessive Inflows

Correction of inflow conditions is dependent on regulatory actions on the part of sewer officials, rather than on public construction measures. If inflows are due to unauthorized connections, correction must be accomplished by surveys which will disclose the presence of such waters; surveillance measures which will locate the actual sources, and action by officials to order the elimination of inflow connections, followed by inspections to confirm such removals.

In cases where illicit or unauthorized connections have been made, officials must examine the effectiveness of their sewer-use regulations and evaluate their sewer, plumbing, and building inspection practices, to determine if these have the power to prevent improper actions and enforce orders to eliminate points of inflow. If violations of clear-cut regulations are found, the effort and cost involved in their correction should be the responsibility of the property owner who made, authorized, or inherited the illicit connections.

In cases where inflow connections were made with jurisdictional approval, or where no positive prohibitions against such physical connections have been included in plumbing, building, or sewer rules and codes, all or part of the responsibility for making corrections may devolve upon the jurisdiction itself.

Concern over excessive inflows often may occur "after the fact" – after it has been found that the volumes of flow exceed what had been anticipated when permissions for inflow connection were issued, or when local agencies failed to enact inflow connection prohibitions. If elimination of existing inflows is deemed necessary because of the adverse effects of these flows on sewer systems, pumping stations, treatment plants, or combined sewer regulator-overflow installations, new or more restrictive sewer-use regulations may have to be invoked.

These are the general factors involved in sewer system inflow. Principles and practices have been expounded here as a preamble to a detailed review of the findings emanating from various surveys of the national study project. Every facet of sewer inflow was covered by the investigation of causes and sources of water intrusion, effects of these flows, and methods used or proposed by jurisdictional officials to overcome the adverse results of these practices.

Recognition of Inflow Problems

Sixty-seven percent of the consulting engineers providing information on the problem of inflow reported that they had been engaged to survey locations and nature of excessive inflows of various waste waters into sewers. This response indicated that the inflow portion of the extraneous water problem is recognized by most consultants and their clients, although both infiltration and inflow are undoubtedly considered as a single volumetric factor. However, when asked if such investigations resulted in the elimination of inflows, fewer than 50 percent replied in the affirmative. This can be interpreted as meaning that recognition and location of inflow may be much simpler than the actual elimination.

During the statistical survey, municipalities were asked if excessive inflow into their sewer systems was a problem. Table 24, National Statistical Survey – Is Inflow a Problem?, summarizes the responses by regions and population groupings.

TABLE 24

NATIONAL STATISTICAL SURVEY
IS INFLOW A PROBLEM?

Region and Population Group	Yes	No	No Answer
East	37	7	1
South	23	4	1
Midwest	24	9	2
Southwest	22	2	1
West	21	30	2
Canada	18	2	1
200,000 +	25	12	2
100,000-199,999	15	15	1
20,000- 99,999	39	53	7
10,000- 19,999	14	16	4
Under 10,000	3	6	1
Total	96	102	15

On a total response basis a greater number of jurisdictions reported no problem. However, one-third of the number supplied no information or indicated that this information was not known. Among the regions of the United States, only the Midwest produced more "yes" answers than "no" answers – by a 3 to 1 margin. As might be expected, the South and Southwest reported a high ratio of "no" to "yes" responses. In general, the results substantiated the in-depth field investigations, finding that municipalities in warmer climates – where slab construction of buildings is predominant – do not experience excessive inflow connections, because of the absence of basement and roof drains.

Analysis of responses on a population basis revealed that large cities are much more aware of, and involved with, the problem than smaller communities. The 200,000-and-over population group gave twice as many affirmative answers as negative, while the under-10,000 group had almost a 4 to 1 ratio of "no" to "yes" responses. Obviously the larger cities, even though many still use combined systems,recognize the impact of inflow connections on the overall capacity and efficiency of their sewers and treatment works.

Sources of Inflow

The 66 consulting firms contacted in connection with the survey of engineering practices gave roof drains the most frequent mention as a source of inflow, as indicated in Table 25, Consulting Engineers' Survey, Sources of Inflow.

It is revealing to find that almost one-third of the respondent consulting engineering firms offered no opinions or answers on this subject. In general, these

TABLE 25

CONSULTING ENGINEERS SURVEY
SOURCES OF INFLOW

Sources	Number of Consultants Reporting
Roof Drains	38
Foundation Drains	34
Basement or Yard Area Drains	32
Industrial/Commercial Clean Water	21
Drainage of Springs/Swamps	20
Other Various	5
No Opinion	19

TABLE 26

NATIONAL STATISTICAL SURVEY
SOURCES OF INFLOW

Population	200,000+							100,000-199,999						
	0-15%	16-30%	31-45%	46-60%	61-75%	76-90%	91-100%	0-15%	16-30%	31-45%	46-60%	61-75%	76-90%	91-100%
Storm Water-Building Sewer	7	5	1	4	2	–	–	8	4	1	2	–	–	–
Storm Water-Manholes	15	2	–	–	–	–	–	10	7	2	1	–	–	–
Ground Water-Basement Drain	10	3	–	–	–	–	–	10	3	–	–	1	–	–
Population	20,000-99,999							10,000-19,999						
Storm Water-Building Sewer	25	6	2	6	2	–	1	5	4	1	1	1	–	–
Storm Water-Manholes	32	3	1	4	2	1	1	12	2	2	–	1	–	–
Ground Water-Basement Drain	8	1	–	–	–	–	–	8	1	–	–	–	–	–
	Under 10,000							Totals						
Storm Water-Building Sewer	5	–	–	1	–	–	–	50	19	5	14	5	–	1
Storm Water-Manholes	6	1	–	–	–	–	–	6	1	–	–	–	–	–
Ground Water-Basement Drain	3	1	–	–	–	1	–	53	17	1	3	1	1	1

represent the percentage of consultants who never have been asked to carry out inflow surveys. The absence of such assignments can be linked to the fact that most jurisdictions reported no involvement with inflow problems.

The 212 jurisdictions surveyed in the United States and Canada supplied their evaluations of the percentages of total excess waste water flows due to specific inflow sources. Table 26, National Statistical Survey – Major Sources of Inflow, presents a summary of findings with respect to storm water entry through building sewers, into manholes, and ground water intrusion through basement drains. Of all sources of excess water entering sewer systems, inflows from four sources were classified as contributing from 90 to 100 percent of the total excess flow. A similar tabulation on the infiltration problem is contained and discussed in Section 4.

Control of Existing Inflow

Referring to restrictions on some specific sources of inflow, the national statistical survey asked if connection of downspouts to building sewers was permitted. Table 27, National Statistical Survey – Are Downspouts Permitted to be Connected?, summarizes the replies from the United States and Canada.

The answers to this question demonstrated an overwhelming prohibition of inflow connections; the ratio was almost 10 to 1. Specifically, only 22 out of 212 permit them. As pointed out in subsequent sections of this report, the direct entry of rain water from roofs is recognized almost universally as undesirable.

TABLE 27

NATIONAL STATISTICAL SURVEY ARE DOWNSPOUTS PERMITTED TO BE CONNECTED?

Region and Population Group	Yes	No	No Answer
East	9	35	1
South	0	28	0
Midwest	4	31	0
Southwest	0	25	0
West	4	54	1
Canada	6	15	0
200,000 +	10	28	1
100,000-199,999	0	31	0
20,000- 99,999	8	91	0
10,000- 19,999	4	29	1
Under 10,000	1	9	1
Total	23	188	2

In contrast, the jurisdictions replied in a significantly different manner when asked if they permitted the connection of basement, foundation, or other drains to building sewers. Table 28, National Statistical Survey – Are Basement Drains Permitted to Be Connected?, summarizes these results on a regional and population basis.

The total replies indicate a 2 to 1 ratio between prohibitions of basement drain connections and acceptance of such inflow waters into sewer systems as against 10 to 1 in the case of roof leader prohibitions. Policy approving basement drains, as noted in other investigations, results from the basic assumption that they may contain waste waters requiring treatment.

TABLE 28

NATIONAL STATISTICAL SURVEY ARE BASEMENT DRAINS PERMITTED TO BE CONNECTED?

Region and Population Group	Yes	No	No Answer
East	25	19	1
South	4	23	1
Midwest	10	25	0
Southwest	5	19	1
West	16	42	1
Canada	17	4	0
200,000 +	18	20	1
100,000-199,999	12	19	0
20,000- 99,999	32	65	2
10,000- 19,999	10	23	1
Under 10,000	5	5	0
Total	77	132	4

Regionally, only the eastern part of the United States and Canada revealed a majority of jurisdictions permitting basement drain connections. The predominance of old systems and old connections in that part of the United States mitigates against strict sewer-use regulations and enforcement. Not a single population category reported a majority of jurisdictions permitting this practice.

Connection of Cellar, Foundation and Roof Drains

The 26 jurisdictions visited by staff investigators were asked if roof leaders, cellar drains, and foundation drains were permitted to be connected to sanitary or combined sewers. No jurisdiction permits roof leaders to be joined to sanitary sewers. However, 10 permit such connections to combined sewers; only two communities do not permit such connections. Three members of the Advisory Committee reported permission for drain connections to sanitary sewers; 10 jurisdictions permit these connections to combined sewers. The connection most frequently permitted was reported to be the cellar drain. Six of the 26 jurisdictions permit cellar drains to be connected to the sanitary sewer, and nine permit connections to their combined sewers.

An evaluation of these responses indicates that roof leaders obviously are recognized as the greatest contributors of storm water drainage to sanitary sewers, and jurisdictions deem this connection undesirable. Foundation drain connections are permitted by a small percentage of jurisdictions, probably because such drains are a requisite for certain private mortgage money and Federal housing grants. In the absence of an available storm sewer system, foundation drains must be connected somewhere and the sanitary sewer often is the most convenient recipient of these inflow waters. Connection of cellar drains is permitted more often because these are not considered an obvious interconnection of ground or storm water into sanitary sewers. However, it is quite obvious that if basement flooding results from intensive rainfall or any other condition of high ground water table, it will be alleviated through the basement drain or the cellar drain directly into the sanitary sewer. Cellar drains, therefore, are an indirect source of ground water inflow.

One jurisdiction made the following comments on the connection of roof, cellar, and foundation drains: "Roof drainage, cellar drains, and foundation drain connections to combined sewers only, are permitted where no storm sewer exists. However, we ask the owners of commercial buildings to provide a separate soil pipeline for such drainage at least out beyond the building wall, where it is tied in with the sanitary pipe. This has the advantage of minimizing the effects of a stoppage in the sanitary soil pipe within the building during storm conditions and it also permits comparatively easy laying of a separate storm drain to the street at any time a street storm sewer is provided."

The Metropolitan Sanitary District of Greater Chicago requires a statement (on all plans for building sewer connections) to the effect that downspouts and foundation drains will discharge into the ground. If this is contrary to local ordinances, the specific reference and the local ordinance must be submitted. The District also stated that no communities discharging into the District System may authorize the discharge of storm water into a sanitary sewer.

One respondent stated that in his jurisdiction it is unlawful to connect roof drains and foundation drains to the sanitary sewer system but that cellar drains may be connected to the sanitary system. He reported: "We consider these floor drains to be primarily for waste water used in cleaning within the building." This is the usual line of reasoning when connection of interior floor drains is permitted, but these drain connections can be seriously abused in practice.

The Areaway Drainage Problem

The in-depth investigations of the 26 representative jurisdictions visited by project representatives brought to light the special problem of draining cellar areaways. In some sections of the country, particularly in areas of Maryland, Delaware, and Virginia, part of the traditional construction of the old housing in the cities included these uncovered basement entries. In some jurisdictions, up to 30 square feet of uncovered areaway is permitted to be connected to the sanitary sewer within the house. Some years ago a number of major cities in the region prohibited such connections but soon found that plumbers or contractors of new homes were illegally making them beneath the basement floor into the floor drain piping. One jurisdiction which conducted an inspection program to expose these connections by visual and manual means reported that steps to enforce removal of such connections eventually were stopped because of homeowner opposition and the objection of local legislators.

As the survey progressed farther into the South, connections of this type were found to be only a minor problem, since many of the homes do not have basements and the roof drainage is allowed to spread out on the surrounding land. In areas where inflow sources are of little significance, jurisdictions find it much easier to detect infiltration because it is not confused with inflow.

As for the connection of storm and ground water through the house sewer, the Advisory Committee was asked if there were many illicit or illegal connections despite local prohibitions. Seventeen reported that such surreptitious entries frequently are encountered. Seven reported none. This response, while initially unexplained, has been found to have validity, especially in areas where connection of such drains is not necessary because of slab-type construction and the absence of basement and foundation drains. Twenty-one jurisdictions reported they have sewer-use ordinances to regulate the discharge of waste water into sewer systems. Four reported that no such regulations are in use. Among those answering that a sewer-use ordinance is invoked, a number said provision is contained in a plumbing code. Plumbing codes, in many cases, are not completely equivalent to an ordinance. These findings indicate there is some confusion as to the function of sewer-use regulations, and that there is need for examination of existing laws, ordinances, and codes covering both plumbing and sewer uses.

Sewer-Use Ordinances and Regulations

The preceding survey illustrates how jurisdictions react to permitting direct inflow connections from building sources. It also underscores the need for better regulation and enforcement. In a survey of inflow control by state and provincial water pollution control agencies, 38 states and four provinces reported they recommend specific policies on sewer-use ordinances or regulations covering entry of extraneous water into sewer systems, while 12 states and four Canadian provinces said they do not become involved.

The survey of consulting engineers asked if they have prepared sewer-use ordinances for client jurisdictions. Almost 50 percent reported that, in the process of conducting infiltration and inflow investigations, they recommend or draft such ordinances.

In the conduct of the national statistical survey, the jurisdictions were asked if they have enacted sewer-use ordinances. Table 29, National Statistical Survey – Sewer-Use Ordinances, contains a summary of the responses.

Only 10 percent of respondent jurisdictions reported the absence of such regulations; another 10 percent supplied no information. In most regions, including Canada, positive responses ran 10 to 15 times higher than no-regulations responses. The East reported the lowest ratio – 5 to 1.

TABLE 29

NATIONAL STATISTICAL SURVEY
SEWER-USE ORDINANCES

Region and Population Group	Yes	No	No Answer
East	37	7	1
South	23	4	1
Midwest	33	2	0
Southwest	22	2	1
West	52	4	3
Canada	18	2	1
200,000+	38	1	0
100,000-199,999	25	5	1
20,000- 99,999	86	11	2
10,000- 19,000	28	3	3
Under 10,000	8	1	1
	185	21	7

Only one city above 200,000 population reported no ordinance enacted; all those surveyed in the under-10,000 class listed such codes or regulations.

Obviously, sewer-use ordinances have been widely adopted for more reasons than inflow control. Nevertheless, examination of sample ordinances usually reveals some reference to elimination of "clean-water," or storm, ground, or commercial water.

When the surveyed jurisdictions were asked if sewer-use ordinances will be adopted or modified, the responses were evenly divided among those who said such action is contemplated, reported no such plans, or were uncertain. Weighed against initial findings on the ordinances in effect, the replies on future action must be interpreted to mean that one-third of the jurisdictions contemplate some code revisions while a lesser number will adopt sewer use ordinances for the first time.

The statistically surveyed municipalities also were requested to comment on the quality of sewer-use ordinance enforcement and indicate who bore the responsibility for it. The respondents generally were non-committal about enforcement, with only nine saying it was done and 10 saying it was not. The balance submitted no commentaries, perhaps not wishing to judge the situation.

However, all answered the question concerning responsibility. In some cases jurisdictions reported

TABLE 30
NATIONAL STATISTICAL SURVEY
RESPONSIBILITY FOR ENFORCEMENT OF SEWER-USE ORDINANCES

Plumbing Inspector	**78**
Sewer Agency	**77**
Other Agency	**47**
Building Inspector	**35**

that joint agency control was invoked. Table 30, National Statistical Survey-Responsibility for Enforcement of Sewer-Use Ordinances, tabulates total responses.

This breakdown clearly emphasizes the existence of overlapping and at times misplaced responsibility not only in building-sewer control but even in the broader area of sewer uses that are not primarily the concern of plumbing and building departments. The almost even split of authority between sewer agencies and plumbing inspectors explains the lack of specificity in reporting positive enforcement.

When these jurisdictions were asked if surveillance would be tightened, 115 answered "yes" and 42 "no" while 63 made no comment. A trend to raise the level of enforcement is indicated here, but the confusion of jurisdiction and the unpopularity of surveillance tend to mitigate against successful action.

A number of jurisdictions supplied information on their regulatory practices and sample form letters used in enforcement activities. One city reported that it threatens to disconnect the house from the sewer if illegal inflow connections are not removed. Another city threatens ultimate court action if voluntary compliance is not achieved; however, the respondent official admitted that such drastic measures would not have an economically justifiable result. Community pressures and individual public opinion as well as economics are in evidence as factors limiting effective enforcement of sewer-use regulations.

Since controling inflow involves undoing physical connections made either with local authorization or illegally, it requires a multiple approach of laws, surveillance, enforcement, and expenditure of public and private funds if it is to be effective. In any case, public support of any program to eliminate building inflow connection is an absolute necessity. Without property owner participation any corrective attempt will meet with disfavor, distrust and dispute.

TABLE 31
CONSULTING ENGINEERS SURVEY
INFLOW CORRECTION BENEFITS

Reduced pumping loads	**32**
Reduction in sewer surcharges	**30**
Reduced treatment plant flows and bypassing	**28**
Reduced combined sewer overflows	**12**

Benefits of Correction

Consultants were asked to list the most important beneficial results of an effective inflow control program. Table 31, Consulting Engineers' Survey – Inflow Correction Benefits, lists the findings.

The consulting engineers demonstrated they were aware of the need for, and value of, determined efforts to reduce inflow which in some systems can produce extremely high volumes of "clean water." Such waters adversely affect all parts of the system.

SECTION 6

JURISDICTIONAL EXPERIENCES

Investigations and surveys conducted under the national study project brought forth many communications, technical articles, reports, and other documents that illustrate actual infiltration and inflow conditions in jurisdictional sewer systems and waste water handling and treatment installations. Beyond the basic data from these local agencies, as described in other sections of this report, efforts were made to obtain such documents and reports and examine them for data on jurisdictional practices, policies and performance in sewer system planning, design, management, and maintenance.

These engineering documents, prepared by consulting engineering firms or local technical personnel, have a great deal of pertinent information. They disclose the upsurge of interest in the infiltration-inflow problem on the part of jurisdictions and their efforts to explore ways of eliminating or minimizing the adverse results of excessive extraneous waste waters entering their sewer systems.

To make some of these interesting and informative facts a matter of record, the following selected excerpts from case histories of the listed jurisdictions are included in this project report. Hopefully, these experiences will be of value to other local community officials faced with similar problems and conditions.

Dade County, Florida

A letter from a consulting engineering firm described infiltration problems in the sewer system serving Dade County, Florida and contiguous communities:

It was estimated in April, 1965 that the total ground water infiltration into the system approximated from 1.8 to 2.0 million gallons per day. At that time, plant flows were averaging 3.3 to 3.5 mgd. Sewer repair work effectively reduced the volume of infiltration to a point where during the month of January, 1967 the average flow was down to 2.0 mgd. During the first two weeks of February, 1967 an accidental break in one of the sewer lines resulted in an increase to a rate as high as 3.3 mgd. After this break was sealed, however, the flows were recorded at or below 2.0 mgd. The normal rated capacity of the plant is 2.05 mgd, or approximately 5,900 single-family residential connections or their equivalent, based on design flow allowances of 350 gpcd. There are presently 4,800 equivalent residential connections active in the system, indicating that an additional 1,100 could be served before the total capacity is utilized – if ground water infiltration can be controlled to the extent realized during recent flow recording periods.

Emmetsburg, Iowa

A paper prepared by a consulting engineering firm described the infiltration problems of this community of approximately 4,000 population. Infiltration resulted in basement flooding during periods of heavy rainfall; sewage treatment plant overloading, which necessitated by-passing; heavy deposition of sand and other debris in the sewer system, and reduction of the carrying capacity of the entire system. The city finally decided that something had to be done.

With the help of an engineering support organization, the city analyzed its entire system and initiated a program of correction. The sanitary system comprises approximately 85,000 feet, or 16 miles, of sanitary sewers, ranging in size from 6 to 20 inches. About 290 manholes are in the system. In addition, there are some 100,000 feet of storm sewers ranging in size from 12 to 48 inches. During periods of heavy rainfall and high ground water, infiltration exceeds the maximum capacities of the sanitary sewers. The objective of the survey was to answer these questions: Where in the 16 miles of sanitary sewers do we start looking for the infiltration problem? How do we relieve the flooded basement situation? On what hydraulic basis do we design modifications to the waste water treatment plant? How do the restricted sewers affect the flooded basement problem? Are the lift stations adequate to handle the flows expected? How much money will be required to solve all these problems?

A multi-phased program had to be established to accomplish the goals, similar to that referred to in Section 4 of this report. The conclusions based on the studies were as follows:

1. Of the 84,839 feet of 6- to 20-inch sewers physically inspected, approximately 35,592 feet, or 42 percent of the system, needed major cleaning.
2. The general nature of restriction in most of

the sewers was found to consist of sand and sludge, with some root penetration evident. The conventional method of bucketing was required in all districts, but the high velocity jet could be used in varying degrees where the top of the deposition allowed.

3. It was estimated that 1,461 to 1,928 crew-hours of cleaning were needed to restore self-scouring velocities to all the sewers inspected and thoroughly prepare them for the TV inspection.
4. As a result of a rainfall simulation study, areas to be televised in quest of infiltration were isolated. These areas were the first to be cleaned.
5. To clean the sanitary sewers in which infiltration was found would require 516 to 645 crew-hours; 28,218 feet are involved, or about 33.3 percent of the total system.

Flint, Michigan

In September 1969, a preliminary draft of a report entitled, "Study of Sanitary and Storm Sewer Systems," was presented to officials of the city. This study comprehensively reviewed existing storm and sanitary sewers, with flow measurements, visual inspections, and many analyses by the consultant to determine the course of future action for the city. Some of the conclusions and recommendations are pertinent to the national study:

- Reduction of the amount of extraneous flows to the sanitary system, modification of the downstream section of the west side interceptor, and separation of the combined sewers in the downtown area would eliminate overflows to the river.
- With few exceptions, the major sanitary sewers in the city have sufficient capacity for future flows, if the entry of excessive extraneous flows is reduced. The importance of accomplishing this work was stressed. The need for greater attention to repairs and maintenance was apparent, particularly in the terminal chambers of the inverted siphons and in defective manholes.
- Investigation showed that extensive areas of roofs and pavements were connected into the sanitary system tributary to a major pumping station. Elimination of the major sources of excessive flow was determined to be practicable and essential to the efficient development of the sewage conveyance and treatment facilities and reduction of overflows from the northwest areas.

It was determined that:

1. Most basement flooding incidences are associated with defects in house drainage systems in areas affected by ground water. In only a few instances would flooding problems be reduced greatly by increasing the capacity of the storm or sanitary sewer systems. Other more effective and less costly measures to alleviate basement flooding are available.
2. Systematic measures should be taken to detect and eliminate sources of excessive extraneous flows into the sanitary sewer system due to discharges from roofs, pavements, watercourses and ground water reservoirs.
3. Regulations should be enacted to prohibit the future connection to the sanitary sewer system of exterior foundation drains or other sources of surface water or ground water.
4. The staff assigned to sewer system and plant maintenance and to laboratory duties should be expanded and additional funds provided to maintain and operate the system properly.

Hutchinson, Minnesota

Hutchinson, population 8,500, has a sewer system of approximately 130,000 feet, or 26 miles, of 8- to 15-inch lines, plus 28,000 feet of interceptor lines ranging in size from 15 to 24 inches. As an aftermath of a flood in 1965, about 22,000 feet of 8- to 15-inch sanitary sewer lines were cleaned and repaired. At that time this was about 22 percent of the sanitary system.

The engineer reported at a recent sewer management seminar that his department will be cleaning and televising about 21,000 feet of sewer lines prior to a proposed two-year street paving program. When this is completed, 43 percent of the system will have been cleaned and televised.

In addition to using TV cameras to determine the extent of flood damage, the city has extended the technique to buying what is described as "paving insurance." In conjunction with a $1.5 million paving program, the cost of cleaning and televising sewers will be about $20,000, considered to be an extremely worthwhile and minimal expenditure.

The greatest value of television lies in the inspection of new sewer construction. The city engineer is convinced that its use has provided the city with high quality construction.

The city considers the TV expenditure a part of the engineering services; it should not be paid for by the contractor as part of his bid. There are too many instances when re-televising of a particular section is necessary. With the city assuming this function, it has complete control of the time of inspection and the subsequent review of the reports.

On a recent project the contractor paid approximately $4,600 to seal leaks on a construction project, plus whatever costs were entailed in the physical replacement of the few broken pipes. The city did not have to bear this burden. The city's expenditure of $900,000 (plus interest which will almost double the figure) for its new interceptor sewers was for quality work, as all of the pipe was inspected.

Milwaukee, Wisconsin

In 1968 and 1969, the City of Milwaukee carried out "an in-depth review of sewer cleaning problems as it relates to municipal services." A report on this survey was prepared by the Bureau of Street and Sewer Maintenance. (Excerpts from this report are contained in the Manual of Practice which is an integral part of this national study report.) Although this study was mostly concerned with the problems of providing top quality maintenance procedures and personnel, there was a definite correlation between proper preventive maintenance and reduction in infiltration problems. There also was a connection between the cost of correcting infiltration and the ability to provide clean sewers for inspection and correction activities. The report pointed out that as the mileage of the total sewer system increases, the average "capacity index" of the municipality decreases. As the city gains in size, its ability to pay the cost of an effective sewer cleaning program fails to keep pace. Historically, it pays more attention to the more obvious above-ground defects and overlooks the "hidden" obsolescence underground – regardless of the continuing proportion of "need." The only exception lies in the "official acceptance" of a priority for sewers that is the same as those assigned "above-ground" urban problems.

The report recommended greater recognition, not only of the problem involved in maintenance and control of infiltration, but of the importance of the people called upon to provide these services. It urged that: "To improve morale, steps should be taken to erase any sense of 'second class citizenship.' A sewer maintenance reorganization study should be made and serious consideration given to the relative importance of the sewer services being provided and the technical skill and knowledge required to get the job done. Appropriate pay scales and titles should be assigned that will tend to equalize 'citizenship status' among all public works employees."

New Providence, New Jersey

In 1964, the Borough of New Providence engaged a consulting engineer to prepare a report on "The Investigation of Infiltration in the Borough of New Providence Sanitary Sewer System."

The New Providence system has 41 miles of sewers with a replacement value estimated at $3 million. It was reported that infiltration and leakage always had been inherent in the collection system and was not a recent occurrence. In newer portions of the system, pipe and jointing procedures were reduced resulting in a decrease in the proportion of domestic and industrial waste infiltration, instead of increasing as the collection system grew. Present leakage and infiltration amounts to an average of about 200,000 to 250,000 gallons per day, or some 15 percent of the average daily flow. In a very wet month, infiltration will range from 300,000 to 400,000 gallons per day, and drop during extremely dry periods to as low as 100,000 gallons per day.

If the borough had a relatively tight sanitary sewer system, utilizing the most effective joints, it was estimated that the system flow would average 1.05 to 1.1 instead of about 1.3 mgd. Likewise, it was believed that in the maximum months the flow would be reduced from about 1.8 to 1.4 mgd. There would be little reduction in flow during the minimum months since little infiltration occurs in dry-weather periods.

The report stated: "Based upon records for infiltration control, and on the assumption that 70 percent of the borough system would require repair, it was estimated that the approximate cost of sealing and repairing of joints in the collection system would range from $225,000 to $375,000. It was also estimated that this repair might reduce system leakage by 150,000 to 200,000 gallons per day, the equivalent of 55 to 73 mg per year. This would be equivalent to an average annual expenditure of from $11,250 to $18,750, or from $200 to $350 per million gallons per year."

The report called for continued investigations and advanced methods of inspecting existing systems to correct excessive amounts of infiltration and inflow.

Oakland County, Michigan

In 1967, Oakland County's Department of Public Works carried out a "Drain Tile-Test Pilot Project," initiated upon a request by building developers to connect building tile drains and foundation drains to the sanitary sewer system and the building sewers. Over a period of one and a half years, numerous flow records were made and correlated with rainfall measurements. The report concluded that the subdivision contributed peak flows exceeding design flows and that therefore the development had a detrimental effect on the system. The staff of the Oakland County Public Works Department concluded that the major cause for this subdivision's difficulties was the clay soil underlying the area. A somewhat similar test subdivision in a sandy soil area contributed no flow to the sanitary system because most of the rainfall percolated past the tile to the deep water table, instead of being held in a pocket as in the case of the clay soil area.

The report recommended that all buildings installing drain tiles be prohibited from connecting directly or indirectly to certain interceptors.

Later tests made on a series of individual buildings, as well as a former research project, indicated there was a direct connection between rainfall on roofs discharged onto ground adjacent to foundations, and the flow of ground water into sanitary sewers from the drain tiles. It was found that severe infiltration flow problems existed when roof leaders discharged next to the foundation walls. Installation of splash blocks diverted the flow about 5 feet into the yard area and effectively eliminated the infiltration of such flows into foundation drain tiles.

Elko, Nevada

In 1968, Elko engaged engineering consultants to prepare a water and sewage Master Plan. Part of this required planning for sewage flow and treatment. The consultants' basic assumptions are given in the following tabulation:

	Existing	Master Plan Conditions
Year	1968	1985
Sewage Flow		
Av. daily dry-weather flow in gallons	1,500,000	2,200,000
Per capita flow – basic population	172	160
Estimated infiltration flow (gpd)	1,800,000	2,800,000
Peak dry-weather flow	1,800,000	2,800,000
Sewage Characteristics		
Biochemical oxygen demand (mg/1) (5-day–20 degree centigrade)	140	160
Per capita equivalent BOD (lbs. per day)	0.20	0.22
Suspended solids (mg/1)	115	140
Grease (mg/1)	37	40

The consultants pointed out that the relatively low BOD concentration reflected the dilution caused by infiltration of ground water into the collection system. Otherwise, sewage characteristics were typical of domestic sewage.

The consultants made the following comments on the existing sewage system: The existing sewer system consists of 157,000 lineal feet of trunk collection sewers, sewage lift stations, and an existing waste water treatment plant with ponds.

Collection sewers primarily are vitrified clay pipe with poured bituminous joints. Some recent construction has utilized concrete sewer pipe. Except for a few recent systems using 6-inch pipes, the minimum size of collection sewers is 8 inches. No serious collection sewer capacity problems are evident. A continued program of cleaning, using the city's high-pressure hydraulic equipment, will minimize collection sewer problems.

The high per capita sewage flow rate and the low organic strength of sewage indicate there is substantial infiltration into the collection sewer system. Considering the high cost of multiple pumping and treatment of sewage flow originating in the low-lying areas adjacent to the river, a program to minimize infiltration from these areas appears justified.

Lexington, Kentucky

Lexington, Kentucky in 1957, carried out investigations and studies of infiltration into the sanitary sewer system of the Idle Hour subdivision in that city. Consultants were asked to investigate and report on the apparent infiltration of storm and ground water into a sewer system consisting of approximately 24,000 feet of 8-inch vitrified clay pipe collector sewers, 700 feet of 4-inch cast iron force mains, and 4,800 feet of 6-inch cast iron force mains.

One conclusion of the report was that: "As a result of the various investigations and studies described earlier in this report, the conclusion is reached that there are two main sources of infiltration into the system. One of these sources is infiltration; that is, ground water which is seeping into the sewer system through joints or holes in the pipe and manholes. The other source, which seems to contribute the greatest amount of excess water, is surface or storm drainage; that is, water other than sanitary sewage which is either piped into the system or gets into the system from standing on or around manholes."

There are numerous locations where foundation drains either are pumped by sump pumps or flow by gravity into the sewer system. In some cases the foundation drain and underdrains are connected into the sumps from basements. But in cases where there are no basements, the water flows from under and around the houses by gravity into the sewer or is pumped into the sewer by sump pumps. In a few other instances it was apparent that roof drains were connected into the sewer. These drains go into the ground without any indication that they discharge at the street or onto the ground.

The consultants recommended that all the foundation drains, basement underdrains, and roof drains be disconnected from the sanitary sewer system; that the manhole deficiencies be remedied, and that all sewer line and house or building sewer connections should be excavated at points where investigations revealed an apparent excessive amount of infiltration. It was discovered during the course of the investigation that "Y's" and "T's" left for connection in the street sewers were, in many cases, not used; that holes were simply punched in the street sewer to allow insertion of the building sewer consultants recommended that all suspicious connections of that type be exposed and reconstructed.

Lincoln, Nebraska

Recently Lincoln, Nebraska engaged consulting engineering services to investigate certain areas that have caused sanitary sewer flow problems. In each investigation, water consumption records as well as weir measurements were used to determine the condition of sewage flow at various times of the day and year.

In one study, three possible problem sources were listed: (1) inadequate sewer capacities; (2) poor sewer flow characteristics, and (3) excessive discharge rates from commercial operation. After investigation and analysis, the following conclusions and recommendations were submitted:

1. Comparison of actual measured flows with winter-quarter water consumption did not indicate cooling water being discharged into the sewer system.
2. Flow metering disclosed some storm water infiltration during a 1.26-inch rain of moderate to light intensity occurring on May 7, 1969. Since the maximum flows were not excessive, it was decided that smoke bombing of the study areas did not appear to have significant value.
3. Flow measurements definitely showed that the sewer on Adams Street is critically overloaded from time to time because of wash-down operations at a local commercial establishment.

Another survey in a different area listed the following as possible problem sources: (1) inadequate sewer capacities; (2) excessive cooling water discharge into the sanitary sewer system, and (3) excessive storm water infiltration.

Comparison of actual measured flows with winter-quarter water consumption indicated discharge of cooling water into the sewer system. At this time, the cooling water is not the primary cause of problems in the area; however, increased discharges into the sewer system could cause future problems. The city was urged to discourage this practice.

Flow metering did not disclose any excessive storm water infiltration in the area during a 2-inch rain of moderate to light intensity occurring on September 16, 1968. Because of this, it was decided that smoke-bombing the study area would not be of significant value.

A third study in Lincoln presented the following factors as possible causes of infiltration problems: (1) connection of roof and area drains to the sanitary sewers; (2) footing drains connected to sanitary sewers; (3) excessive amounts of cooling water being discharged to the sanitary sewer; (4) excessive infiltration through the ground water surrounding the pipe in the downstream portion of the system, and (5) insufficient capacity in a part of the system.

A complete program of smoke-bombing was recommended for this area on all lines built prior to 1926, in view of the problems found in the areas checked. Measures to eliminate illegal area drain connections and broken lines were urged.

The consultants urged that consideration be given television inspection of the older sewers in the area to determine the condition of the lines. Defective joints increase infiltration, permit root intrusion, and add to maintenance problems. It was recommended that houses having faulty venting revealed in the smoke-bombing should be notified so that they immediately can take corrective steps.

Southeastern Michigan, Six-County Metropolitan Area

In 1964, a team of consultants submitted reports to a 6-county committee in the Detroit area regarding a sewage and drainage study. This report comprehensively reviewed many factors in carrying out master planning activities far into the future for this large regional area. Among the many factors discussed was the importance of the infiltration and inflow problem.

The report pointed out that if storm, surface, or ground water is admitted into a separate sewer, there can only be one result – flooding of the system and connected basements. This was best illustrated by the fact that a population of 2,000 people living on an area of 200 acres requires a separate sewer of 12-inch diameter with a capacity of 1.20 cfs. A storm sewer for this area would need to be 60 inches in diameter with a capacity of 120 cfs. As a further illustration, a one-inch hole in a manhole cover, flooded with 6 inches of water, will admit 8 gallons per minute, the equivalent of a sewage flow from 10 homes.

Separate sewers can function satisfactorily if each of the following conditions is met: all sewers, including house connections, are constructed with watertight joints; all manholes are of watertight construction and with covers of the solid type; all roof water and surface water are excluded by ordinance from the separate sewer system; by ordinance, footing drains below the normal ground water table are excluded from the separate sewer system; adequate inspection is provided by the responsible authority to assure compliance with the ordinance; adequate maintenance of the sewer is provided by the authority.

The engineers noted that the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers in its "Recommended Standards for Sewage Works," under design of sewers, type of system, stipulates that: "In general, and except for special reasons, the reviewing authority will approve plans for new systems or extensions only when designed upon a separate plan, in which rain water from roofs, streets, and other areas, and ground water from foundation drains are excluded."

Redding, California

In 1967, a consultant submitted a report to the City of Redding on "The Sources and Correction of Infiltration." The report concluded that:

1. Wet-weather flows in Redding's sewer system are as much as five times the dry-weather flows. This is due to infiltration and as a result the capacity of the system is exceeded.
2. While the quantity of infiltration is relatively easy to measure, locating its source is very difficult. The older portion of the system constructed from 1890 to 1940 contains about 127,000 feet of lateral and trunk sewers and about 90,000 feet of connection or building sewers. The former are municipally owned; the latter are privately owned. The heaviest infiltration flows take place in these older sewers, particularly those which cross or are near drainage channels.
3. Using a television camera, a "pilot program" of internal viewing was conducted in representative portions of the older system. In addition, some pipe and joints were exposed for external examination. Defects found included broken pipe, root infestation, poor connections, and poor joints. Projecting the results of the pilot program to the total older systems, it is estimated that from 30 to 40 percent of the pipe is in need of some sort of repair.
4. Methods of correction include: (a) chemical grouting (which may be preceded by root treatment); (b) excavation and repair, and (c) abandonment and replacement.
5. Total estimated cost of the repair program, which included lateral and trunk sewers, connection sewers, manholes, and additional internal viewing, was $433,000; consisting of $319,000 for municipally owned facilities and $114,000 for privately owned building sewers.
6. The work could be conducted in stages, utilizing city forces to a large extent. If staged, it should be pursued actively or it probably will not be done.

The report recommended:

1. A state program of correction should be initiated. This should start with a systematic and thorough investigation of all known or suspected sources of major infiltration – primarily at drainage channels. As these are found, repairs or replacements should be made. Later stages of this program will consist of root treatment and chemical grouting.
2. All existing abandoned sewers should be investigated and checked to make sure they are sealed off from the active system.
3. As areas change in use or undeveloped lands are developed, the city should relocate and replace all old sewers, particularly below the ground water table.
4. The city now has good standards for the installation and inspection of new work. These standards should be rigidly enforced so that no new sources of infiltration are created.

Another point made in this report was that design capacities are going to be exceeded. One particular interceptor sewer was designed with sufficient capacity for the estimated ultimate population of its surface area, provided that new tributary sewers are properly constructed and that existing infiltration flows can be reduced. On the other hand, if existing infiltration is not reduced and if infiltration is allowed to increase in other parts of the system, it will be necessary to parallel this sewer in the future. It also would be necessary to provide sewage pumping and treatment facilities far beyond those anticipated. Obviously, this situation is not economical, and a substantial reduction in infiltration must be achieved.

Oakland and Berkeley, California

A recent study of "Storm Water Problems and Control in Sanitary Sewers in Oakland and Berkeley, California," was prepared by a consulting engineering firm, under a contract with the Federal Water Quality Administration, covering the East Bay Municipal Utility District No. 1, with assistance from the two cities. The problem and the study area were described as follows:

> "Infiltration into sanitary sewers has plagued engineers and municipal officials for many years. Every sewer system is subject to infiltration to some degree, depending upon the condition of the sewers, the level of ground water, and the soil conditions. The extraneous flows from infiltration into sewers use up valuable hydraulic capacity. Subsequently, such flows reduce the treatment capability of water pollution control facilities by creating abnormally high flow rates. High flow rates upset biological activity. Storm water infiltration results from the use of inadequate construction materials, poor construction practices, and direct connections. Until recently, sewer construction materials and practices were frequently conducive to infiltration because poor joints were produced when the pipe was laid. Rigid jointing materials fractured during pipe settlement, permitting ground water to enter or sewage to escape the pipe. With improvements in construction materials such as flexible plastic joints, the problem of infiltration in recent sewer construction is greatly reduced. However, sewers that were built before the improvements in construction materials and methods were developed – around 1960 – have many years of useful life remaining, and it is not likely that they will be replaced before the end of that useful life is reached. Direct connections, such as roof, yard, and foundation drains, add to the quantity of infiltration, especially during wet weather. In many instances, these connections are not only difficult to locate but also difficult to disconnect because of the political ramifications involved. For these reasons, the general problem of infiltration will continue for many years."

Attempts were made during the course of the investigation to estimate the volumes of storm water infiltration. It should be pointed out that the terminology used in this East Bay study was slightly different from that of the APWA project report on infiltration. In the East Bay study, infiltration includes both classical infiltration into leaking pipes and what has been called inflow, or the direct connection of extraneous water. The report concluded, among other points:

> "Infiltration ratios (the volume of infiltration to the volume of rainfall) were defined both for gross infiltration and for infiltration from each of two sources: percolation and direct connections. The gross infiltration ratios for selected study sub-areas range from 0.01 to 0.14 depending upon land use topography and age or condition of the sewer system. The drainage area that contributes directly to pump station "A" was found to have a ratio of 0.246, about 60 percent of the infiltration was attributable to percolation and 40 percent to direct connections for the eight sub-areas evaluated."

In the course of the study it was found that 11.1 percent of the total volume of rain falling on the East Bay area enters the sanitary sewer system. Approximately 30.6 percent of the total volume of infiltration is contributed by infiltration and runoff from those areas which have combined sewers, composing 4 percent of the study area. About 3.7 percent of the total volume of infiltration is contributed by Pump Station A Drainage Area, composing 1.4 percent of the study area. In the remaining 94.6 percent of the study area, approximately 26.2 percent of the total infiltration is contributed via direct connections and 39.5 percent via percolation or pipe leakage.

The consultants pointed out that because of political ramifications, lack of full cooperation from the citizenry, and apparently because of special soil-condition problems in the area, elimination of illicit or direct connections from private property would not be a practical solution—although a selective program would be of value. It was recommended, however, that all catch basins be disconnected from sanitary sewers.

The report stated, "No single action, short of total sewer replacement, could be found to solve the infiltration problems." A series of component solutions was evaluated. The most practical and the least costly combination of these was concluded to be the following: "(1) Complete about 50 percent of the remaining sewer separation program; (2) provide improvements to the water pollution control plant; (3) locate and disconnect catch basins that are presently connected to the sanitary sewer system; (4)

provide partial treatment for the remaining overflows; and (5) eliminate sewer system bottlenecks." It was suggested that such a plan would take about seven years to complete.

City of St. Claire Shores, Michigan

In 1968, the city engaged consultants to evaluate its interceptors and examine problems of basement flooding. The subsequent report discussed the basement flooding problem as follows: "Elimination of basement flooding will occur when all sources of storm water entering the sanitary sewer system are eliminated." Possible sources of storm water are: (1) storm sewer catch basins and/or roof conductors connected to the sanitary sewer; (2) broken or improperly constructed sanitary sewers, and (3) surface water infiltration via weep-tile (footing drains) at homes with basements.

The city engineer has instituted a program to locate and eliminate storm water connections from storm sewers, catch basins, and roof conductors. Residential roof conductors have been eliminated, and extensions have been required by city ordinance to discharge storm water away from the basement wall. The city has started a program to inspect, determine the amount of infiltration, and repair joints in the sanitary lateral system. The report mentioned the studies that were made by Oakland County Department of Public Works. Data for six locations after a storm on December 21, 1967, are listed as follows: (1) The peak rate flow for sample points which has footing drains connected to the sanitary sewer was 2.6 to 5.2 times the design flow of 0.4 cfs/1000 population (260 gallons per capita per day); (2) the peak rate of flow for sample points which did not have footing drains connected to the sanitary sewer was 1.3 times the design flow of 0.4 cfs/1000 population.

Springfield, Illinois

In 1966, the Springfield Sanitary District instituted a program of downspout removal from sanitary sewers. This was administered by the Sanitary District staff. The project report states: "The quality of sewer construction has been under close scrutiny during the past few years. Allowable infiltration or exfiltration has been drastically reduced. As a result, considerable improvement has been made in sewer jointing in an attempt to meet these more stringent standards. While improvement in construction practices is certainly to be encouraged, we can hardly hope for the changes in construction practice to bring improved results in our sewer systems unless the other factors which cover overloading of the sewers are also properly considered and corrected.

It must be remembered that in a normal community, the footage of house services is far greater than the street sewers. Too often, poor inspection, or no inspection, is made of the house services with the result that they contribute considerable volumes of water to the sewer system through infiltration. Also in many places footing tiles discharging to the sewer systems are legally or illegally constructed around buildings. In many places roof downspouts are also discharged to the sewers either legally or illegally and they also contribute considerably to the hydraulic loading of the sewers. It, therefore, seems quite inconsistent to demand a high degree of construction quality in the street sewers without also preventing the entrance of surface and ground waters into the same sewer system from other sources. While the control of extraneous waters into the sewer system from these other sources may be much more difficult to control than the construction practices on new sewers, they must be controlled if we are to make the present construction practices meaningful and productive in reducing the volumes of superfluous water that presently reach our sewer systems."

The District investigated the existence of downspout connections by actual on-site inspections and by the use of questionnaires. After establishing the possibility of certain homes being in violation, a series of letters were sent to the homeowners, requesting compliance with ordinances and regulations. After a series of follow-up inspections, there were further letters to property owners. Considerable success was achieved in reducing downspout connections.

Second inspections revealed that less than 2 percent of the original number of buildings were still connected to the sewers.

The report said the number of downspouts with lapsed connections was a serious problem in these areas. However, the results obtained in reduced basement flooding as a result of the campaign were classified as excellent. Previously the Sanitary District office had received as many as 300 complaint calls in a single day about basement flooding; the sewer construction and downspout campaign virtually eliminated such calls.

Southfield, Michigan

In 1969, consultants submitted a report to the city officials covering investigations of sewer and drain conditions that caused local flooding of streets and basements. The studies were prompted by severe flooding during the major storms of 1967-1968.

The consultants pointed out that in designing combined sewers, engineers calculate that 98 percent of the capacities will be used for storm water runoffs and only 2 percent for sanitary sewage.

This report parallels others prepared for the Oakland County area, where the county department of public works has been a leader in investigating excess water in sanitary systems and in developing corrective measures.

Some steps already had been taken to solve these problems including: design of eight new major drains costing $3.9 million; design and/or construction of several major sanitary subtrunk lines at a cost of additional millions; the replacement of perforated manhole lids in certain critical areas; and expansion of the city's ditching program.

The report contained 19 recommendations, with proposed assignments of the responsibility for implementing them. One recommendation was that the city should exert every effort, through meetings, lectures, and written materials, to make citizens aware of the problems connected with flooding due to infiltration and inflow, plus necessary corrective measures.

It was further recommended that:

1. All ordinances relating to the questions of drainage and sewerage be reviewed by the city attorney and the appropriate city department to determine whether such ordinances provide the protection for which they were originally intended, and whether penalties currently provided for are adequate to eliminate repeated violations.
2. Any ordinance or sections of an ordinance relevent to the matter of flooding of sewers which are not enforceable be rewritten in a manner that will expedite enforcement.
3. All ordinances be enforced uniformly.
4. Footing connections to the sanitary sewer system be disallowed.
5. The city hire at least two enforcement inspectors in the building department, whose sole job would be to provide expanded inspection and enforcement of all ordinances.
6. All residents install conductor boots to downspouts or provide splash blocks so that roof water is discharged at least 5 feet from foundation walls.
7. All foundation planting beds, and lawns be graded, or regraded, to provide a continuous 5 percent grade downward and away from any building to a distance of at least 10 feet.
8. Solid sanitary or combined sewer manhole covers be utilized wherever deemed necessary to restrict inflow of storm water, and that such covers are to be removed only by authorized persons.
9. All conventional sump pumps and patio drains be disconnected from the sanitary lines wherever they have been connected illegally.
10. City enforcement inspectors be particularly vigilant in the case of plugs being removed from the sanitary outlets and open basement drains.

Stamford, Connecticut

In 1969, consultants were retained to conduct investigations and report on the capacity and condition of existing sanitary sewers in Stamford.

Investigations used city employees to reduce the time for the study. Each manhole was opened in the study area, and the flow and condition of pipes were recorded. Approximately 25 percent of the manholes in the study area were found buried beneath pavements. Measurement of flows in manholes during both rainy and dry weather was carried out to detect ground water infiltration and/or storm water contribution. Among the manholes studied, one was found to have 140 times the design flow in dry weather, because of continuous ground water infiltration. Other manholes recorded 25 to 35 times the theoretical flow during dry weather. In a number of other manholes the wet-weather flow was two to three times the dry-weather flow, indicating illegal connections.

Pumping station records showed that storm water runoff entered the sanitary sewer system at some points. The rather rapid and abrupt pattern of change of flow at the pumping station, and the pattern of high inflows during rainfalls, led to the conclusion that the runoff entry resulted typically from direct connection of storm water drainage to the sanitary sewer lines rather than from infiltration. It was concluded that the heavy inflow rate was the result of illegal connection of roof or yard drains or an inadvertent cross-connection between the storm sewer system and the sanitary sewer system, or even the location of a sanitary sewer manhole at a point where storm water runoff could flow directly into manholes or pipes.

It was recommended that a comprehensive cleaning and repair program be instituted; that all abandoned house services and illegal connections be plugged; that a television survey be made to determine where faulty pipes and joints are located;

that repair of manholes and installation of watertight manhole covers be instituted, and that there be smoke testing of sanitary sewers to detect illegal connections.

A budget estimate for this work was developed, assuming that all parts would be cleaned and also that not more than 50 percent of the pipe joints would require repairs. With an added dollar amount of $3,000 per mile of sewer for incidental repairs, it was estimated that implementation of the recommended procedures would cost about $300,000, or 4.6 percent of the city's investment in these sewers, represented by an estimated total replacement cost of $6,500,000.

It was suggested that a system of "monitored manholes" be established throughout the city. Selected manholes at key positions should be monitored manually or with recording instruments to detect the presence of major infiltration and major changes in flow. This might indicate, among other things, approaching inadequacy of given sewers, or illegal connections.

Stonybrook Regional Sewerage Group, New Jersey

In October 1969, a consulting engineering firm submitted a report on recommended waste water collection and disposal facilities for a group of municipalities surrounding Princeton, New Jersey. Sections of the report related to the infiltration and inflow problem, which is extremely severe in the Princeton system. The consultants drew 32 conclusions from the study. Two of these related to infiltration conditions:

1. Ground water infiltration in the Princeton collection system is higher than normal and is attributable to the materials of construction used in the latter part of the century, when many of the sewers were constructed.
2. There are several locations in the Princeton sanitary sewage system at which overflowing or by-passing of untreated waste water occurs during times of peak flows in the system. The magnitude of peak rates attained in the system is the result of many unauthorized drainage connections being made to the sewers designed as separate sanitary sewers. It would not be practical for the design of the regional sewage facilities to be based on the continuation of these drainage connections.

The extraneous water flows in the system were recognized as being so important that an entire chapter was devoted to a discussion of peak flow rates encountered in the Princeton sewer system. Hydraulic studies indicated that the peak flows reached a rate of 35 mgd. Since the maximum rate that can be discharged to the main sewage treatment plant by means of the River Road Pumping Station is on the order of 8 mgd, the remainder of the flow is discharged through the pumping station by-pass, overflow pipes in the manholes, and manhole covers in outlying areas. Overflows were as follows: 4 mgd through the pumping station by-pass, 18 mgd through manhole overflow pipes, and 5 mgd through manhole covers.

In discussing the problem of extraneous flows in Princeton the report makes the following comments:

> "The existing waste water collection system owned by the Princeton Borough and Township as well as Princeton University, was intended to be a separate sanitary sewer system. However, through the years many unauthorized connections have been made to the system; this has allowed the discharge of storm sewage and ground water into it from roof and yard drains, foundation drains, sump pumps and other miscellaneous drainage pipes. The net effect of these drainage connections has been the conversion of the collection system into a combined pipe. While many of these connections have been eliminated in the past, a large number of them still remain and exert their influence in the form of higher than normal flows at the waste water treatment plant and surcharge sewers that cause waste water discharges through manhole covers or overflow pipes that have been provided to relieve the overloaded condition."

Concerning the question of correcting infiltration, as opposed to eliminating the inflow of direct storm connections, the consultants stated:

> "As the Princeton sewer system is an old one, dating back to the late 1800's, a significant portion of it was constructed of materials which provide much less resistance to ground water infiltration through pipe joints and manholes than sewers constructed with present day materials can provide. Therefore, it is felt that the greater part of the infiltration is in the system and cannot be reduced through corrective measures. However, efforts should be made to eliminate as many drainage connections as can be located to reduce the load on the sanitary sewage system to the greatest extent possible."

Toronto, Canada

A report of the Commissioner of Public Works of Toronto to the Public Works Committee described methods to eliminate infiltration in some old sanitary sewers. The sewer system is 933 miles in length, with a replacement value of $330 million having an unexpired value of $137 million. A series of investigations disclosed many defects in the existing system. Many of the pipes had developed serious spiderweb or alligator cracking, longitudinal and circumferential cracks, open and displaced joints, hard calcide or grease deposits, and tree root intrusion. It also was found that many of the private drains and building sewers were improperly installed, with the extremity of the drain protruding into the sewer.

Starting in 1965, the City of Toronto began a program of new storm sewer construction, thus removing some of the combined sewers from the system and permitting the older sewer to revert to sanitary use. In 1966, the Commissioner began experiments on the relining of existing sewers with high density plastic pipe liners.

For the initial pilot project, which included development of rotary rooter type equipment and many other onetime charges, the overall unit cost for relining was $50.90 a foot. In subsequent operations the cost was reduced to $22.65 per foot. The commissioner estimated that the conventional open-cut method of complete sewer replacement would cost between $30 and $50 a foot in Toronto. With $35 a foot as a realistic reasonable average cost for complete reconstruction, relining was estimated to cost 35 percent less than replacement.

Wichita, Kansas

In 1961, the City of Wichita, Kansas, engaged consulting engineers to study the problems of flooding as a result of infiltration and inflow in the southwest section of the city.

The report indicated that in 1953 through 1956 the city had installed sanitary sewer mains, submains, and laterals, to provide sewer service to an area of about two square miles in the southwest part of Wichita. The area had a generally flat topography and a normally high ground water elevation. The sewer depth varied from 4 to 17 feet. In most of the area the depth was sufficient to accommodate basement floor drains. Normal rainfall in Wichita is 28.4 inches per year. The rainfall in 1952 through 1956 averaged 18 inches per year, or 10.4 inches per year below normal. In those years the sewers were constructed at a time when the ground water elevation was several feet below normal. The building sewers were constructed of clay pipe and bituminous fiber pipe. Many of the houses had basements. Some houses were constructed as two-story houses, with the lower level approximately 4 feet below the yard grade. In some houses, drain tiles were laid around the foundation with a sump pump in the basement, and ground water was pumped into the sanitary sewer system.

In 1957 through 1961, the rainfall averaged 35.7 inches per year, or 7.3 inches per year above normal and double the average for the preceding five years when the sewers were built. In 1957 the first reports of sewer problems in the area came to the attention of city officials. Residents in this area began to complain of sewage backing up into basements.

Sewers in the area had been constructed in easements along the rear yards. By 1959 cavities began to appear in the rear yards over house sewers and public sewers. These cavities were checked, and the sewers were discovered to be leaking and allowing ground water and soil to enter the sewer system. Nearly all leaks were through joints; very few were caused by cracked pipe. The sewer lines were repaired as each cavity was reported. Many were reported in 1959, 1960, and 1961.

Investigations in 1957 and 1958 indicated that infiltration was entering the sewer system through the tops of the manholes between the rim and the cover, and that some property owners were lifting the covers and allowing ponded water in the back yards to enter the sanitary sewer system. A program of raising the tops of the manholes was initiated to stop this source of infiltration.

In March 1961, city officials met with the Southwest Civic Council to outline the following cause of sewer flooding:

1. Infiltration into the joints of building sewers and public sanitary sewers;
2. Inflow from foundation drains connected to sanitary sewer systems;
3. Flat topography and high water table elevation;
4. Inadequacy in storm water facilities in the area;
5. Lots in the area were not graded to drain to the street, resulting in ponding in the back yards;
6. Property owners were opening manholes, allowing surface waters to flow into the sewer system;
7. Back pressure in the manholes may have caused the joints to become defective, and
8. The home builders failed to provide any backwater devices to protect the homes in the area.

It was agreed that the city should:

1. Maintain continual inspections of the area to find breaks or leaks in the sanitary sewer system or house connections;

2. Study the need for more storm water facilities;
3. Require more rigid regulations relative to building sewer drains, and
4. Provide additional main or interceptor capacity. Property owners should install backwater devices.

Following the meeting, city officials decided to (1) make a house-to-house canvas of the area to seek out other possible illegal connections and explain to property owners the reasons for not draining surface water into the sanitary sewer system, particularly through manholes; (2) smoke-test the sewers and observe the locations where smoke escaped for clues to the points where infiltration occurs; (3) install two observation wells to determine and record the ground water level.

Approximately half of the area was tested with smoke bombs during the summer of 1961. Leaks were detected in 30 of the sewer lines, but were not repaired pending a determination of the problem's scope.

In September 1961, the specifications for house sewers were changed in areas where ground water was encountered. Concrete encasements became a requirement in these areas.

In September 1961, the city began evaluating the possibility of using closed-circuit television to investigate the sewer problem. In a subsequent study, 63 leaks were found and these were repaired. Sixty percent of the leaks were found to be in house lines. Stripes were painted on 57 manholes for the purpose of recording high water in the sewer after a rain.

Many failures in the house lines constructed of bituminous fiber pipe occurred; as each was replaced with other pipe the problem was relieved. The city engineer estimated that about 60 percent of the infiltration was entering the system through house lines, and that considerable improvement had resulted from replacement of defective lines. The major conclusion of the consulting engineer was that the infiltration resulted from many small leaks and there were few or no major leaks in the system. The building sewers were considered to be a major contributing source of extraneous waters. Ultimately it was deemed feasible to construct additional interceptor capacity to relieve the flooding problems.

Winnipeg, Canada

The Metropolitan Corporation of Greater Winnipeg, Waterworks and Waste Disposal Division, and the City of Winnipeg have conducted numerous investigations during the past few years into the problems of infiltration and combined sewer systems in the metropolitan area. In September 1969, a report reviewed the problems of the Rosser area in northwest Winnipeg.

In 1968, a sewer system for this area was installed. Inspection of the sewers after completion indicated that the quality of construction was such that considerable infiltration could be expected. To determine the extent of infiltration, a chart recorder was installed at the pumping station to provide a record of the running time of the pumps. A comparison was made with the average daily water consumption in the area. The following ratios of quantity of sewage flows to the quantity of water delivered was as follows: minimum flow – 3.5:1; average dry weather – 5.0:1; maximum summer heavy rain – 19.4:1, and maximum spring runoff – 153.1:1.

Later in 1968, an inspection was made of the sewers in the area, and television was used on sewers 10 inches in diameter and larger, representing 41 percent of the total tested for infiltration.

As a result of these inspections large flows of water were found to be entering almost all the manholes between the concrete rings. In addition there were 10 locations where pipe joint rubber rings were protruding into the sewer–indicating poor attention to the watertightness of the sewer. The results of the infiltration test confirmed that the installation did not meet required standards for sanitary sewers.

The report recommended that:

1. The city should adopt strict specifications on infiltration allowances and follow up with pressure tests on complete jobs before acceptance.
2. Consideration should be given to correcting the existing system with grouting of manholes where leakage exists and pressure grouting of pipe joints where rings are misplaced.
3. Grades should be more carefully controlled on sanitary sewer lines to prevent future blockage problems.

Another report on the general problem throughout the Metro area pointed out that the sources of "extraneous flow" – additions, over and above normal domestic sewage allowances – may be from downspout, driveway, patio, or weeping-tile connections to the sanitary lines, or any combination thereof. Storm sewer cross-connections and street drainage into sanitary manholes also may contribute to this extraneous flow experienced during storms.

The report stated that Metro must adapt its system to live with infiltration conditions to a degree which reasonably can be controlled, and that it must revise sewer design criteria to include an allowance for a reasonable amount of extraneous flow (over and above the infiltration allowance now included).

Yakima, Washington

In December 1961, the city had a consulting firm conduct a preliminary investigation to establish sewer design criteria and prepare preliminary designs for improvements and additions to the sewage collection and treatment facilities. This study was to include investigation of the infiltration problems in the sanitary sewer system and establish a program for reducing infiltration where economically justified.

The report on these studies said the effect of excessive infiltration is to create additional flow that reduces the sewers' capacity for existing or future sanitary sewage. The flow also adds to the treatment facilities' loads and limits their ability to treat the sewage adequately. This excessive infiltration often necessitates earlier expansion of both the sewage collection system and the treatment plant.

Surface or storm water is another source of flow which, in many systems, was not intended to enter the sewer and exceeds the design sewage flow. This additional flow enters the sanitary sewer in Yakima through roof and foundation drains, holes, manhole covers, and cross-connections between the storm and sanitary sewer systems.

The report described exfiltration as a source of pollution in the ground water table. It urged reduction of exfiltration effects by proper maintenance.

The flow at the treatment plant caused by infiltration ranged up to an estimated 15 mgd during the summer months. Although it is common to expect variation in sewage flow between high and low ground water periods, the flow from infiltration rarely represents 70 to 80 percent of the total flow over extended periods, as in the Yakima situation. The records in 1962 indicated that total precipitation during the months of high infiltration, May through September, was only 1.8 inches and that no rain occurred during the period just prior to recording the peak flow. Therefore, the entrance of surface water was not considered a major factor in the Yakima sewage collection system, and the infiltration of ground water is the primary contributor to the high flows recorded at the treatment plant.

Treatment plant flow records were found to indicate a definite increase in flow rates when the municipal irrigation system is turned on in the spring, and also a definite decrease when the irrigation system is shut down in the fall. In 1961, the flow at the treatment plant increased approximately 3.6 mgd within four days after the irrigation system was activated. In 1962, the older portion of the irrigation system was activated on March 26; the minimum flow at the treatment plant increased 4.2 mgd within five days and fell approximately 3 mgd in three days, when the irrigation system was shut down for repairs.

The consultants recommended that the city:

1. Include in the annual sewer budget $25,000 per year over the next 10 years for infiltration correction by repairing and replacing existent sewers during the winter months;
2. Initiate the annual infiltration correction program by retaining a sewer grouting contractor to grout the sewer lines internally in the West Mead System Project No. 1;
3. Continue the current photographic inspection program of the sewer system until the entire system is recorded on film;
4. Maintain comprehensive logs of the filmed sewers to develop a list of repair, grouting, and reconstruction projects which can be scheduled annually through the next 10-year period, and
5. Require rigid inspection of all future sewer construction to assure minimum infiltration.

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SECTION 7

BUILDING SEWERS

The building sewer connects the structure served with the main public sewer. The portion of the building sewer between the structure and the property line constitutes one part of the connection. The portion between the property line and the public sewer in the street completes the connection. There is a loss of control governing the installation and inspection of these sewers.

Reference is made to these two portions of building sewers because the separate parts commonly are constructed and connected under the control and supervision of separate governmental agencies. The connection to the building plumbing and drain system that extends to the property line is often interpreted as an extension of the in-structure facilities; it ordinarily is installed under plumbing or building code regulations, and tested and approved by plumbing officials or building inspectors. The section of the building sewer between the property line and the street sewer, including the connection thereto, usually is installed under sewer rules, and inspection and approval are within the purview of public works or sewer officials.

One exception to this rule of split authority often occurs in the case of industrial wastes connections. Because of the possible effect of such wastes on sewer structures and treatment facilities, the entire length of these building sewers may be supervised by sewer officials. In this way they better control such connections and the introduction of wastes, when these are ruled to be amenable to sewer transportation and treatment.

The problems inherent to the divided authority mentioned above were explored during the course of the studies.

Building sewers contribute a large portion of the overall infiltration and inflow volumes carried by separate sanitary and combined sewer systems.

The multiplicity of these lines in any given stretch of collection sewers in heavily built-up urban areas, and the fact that each connection line has two physical connection points – one at the building line and the other at the junction with the public sewer – all contribute to the potential entry of infiltration water into sewer systems.

Building sewers may be the discharge point for inflow connections from roof drains, cellar and foundation drains, basement or subcellar sump lines, or "clean water" commercial and industrial effluent lines.

In terms of infiltration, the relationship between the total length of building sewers and the length of street sewers receiving building flows is often equal to or greater than street sewer length. For example, lots with 50-foot street frontage provide four building connection sewers per side of the street, or eight per 200 feet of block length. If the average building sewer is 25 feet long to the street line, including sidewalk width, grass plot, and carriageway, the total length of these lines will be equal to the length of the street sewer.

A survey of infiltration and inflow control practices of state and provincial water pollution control agencies disclosed opinions that poorly made house connections, illicit house connections, poor house sewer taps, and poor house sewer construction practices were among the known sources of excessive infiltration into sewer systems.

While the opinion is widely held that building sewers contribute a large amount of the total infiltration flows carried by sewer systems, the exact role of these connection lines has not been determined with sufficient certainty to permit drawing definitive conclusions. This is clearly shown in Table 32, National Field Investigations - Estimated Percentage of Total Infiltration Attributed to Building Sewers. The twenty-six of the representative jurisdictional sewer systems investigated by on-the-site interviewers during the course of the national investigation are covered in the tabulation. Estimates of the percentage of infiltration in the total system attributable to building sewers ranged so widely that the validity of any conclusions drawn from these data is subject to some question. Percentage effects ranged from 95 percent at New Orleans, Louisiana, and 75 percent at Baltimore, Maryland, to only 1 percent at Ft. Lauderdale, Florida, 2 percent at Watsonville, California, and 3 percent at Washington, D.C. In Nassau County, New York, the interviewer was informed that infiltration through building sewer connections was "negligible."

The in-depth investigations carried out in the 26 representative jurisdictional systems, with interviewers attempting to obtain all available information, disclosed that nine systems included in the tabulation in Table 32 had made no estimates of

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the effect of building sewer infiltration on the total flow of extraneous waters carried by their sewer systems.

TABLE 32

NATIONAL FIELD INVESTIGATION ESTIMATED PERCENTAGE OF TOTAL INFILTRATION ATTRIBUTED TO BUILDING SEWERS

City	Estimated Percentage
Baltimore, Maryland	**75%**
Bloomington, Minnesota	**25%**
Dallas, Texas	**50%**
Denver, Colorado	**High – No estimate**
Ft. Lauderdale, Florida	**1%**
Jacksonville, Florida	**20%**
Knoxville, Tennessee	**30%**
Milwaukee, Wisconsin	**65%**
Nassau County, L.I., N.Y.	**Negligible**
New Orleans, Louisiana	**95%**
New Providence, N.J.	**0%**
Princeton, N.J.	**60%**
San Jose, California	**60%**
Savannah, Georgia	**35%**
Washington, District of Columbia	**3%**
Washington, Suburban Sanitary Commission	**40%**
Watsonville, California	**2%**
Yakima, Washington	**40%**

Further efforts to obtain specific estimates on this subject from state and provincial water pollution control agencies, consulting engineers, and other involved persons and entities proved relatively unproductive. In Figure 12, Infiltration and Inflow from Building Sewer Connections, are photographs of typical poorly made field connections, allowing infiltration to occur.

Computation of Building Sewer Infiltration

An effort was made to derive guidelines on the extent to which infiltration could be attributed to building sewers in a typical sewer system. The theoretical computation is shown in Table 33, Estimate of Relative Amount of Infiltration from Building Sewers. This computation is based on the two assumptions that: (1) the total length of building sewers in the section of the street sewer used in the computation is twice that of the street sewer, and (2) the building sewers have the same construction quality, in terms of tightness, as the street sewer system.

The sample calculation indicates that, under such conditions, building sewer infiltration could account for 38 percent of the total infiltration into the entire

TABLE 33

THEORETICAL COMPUTATION OF ESTIMATE OF RELATIVE AMOUNT OF INFILTRATION FROM BUILDING SEWERS

ASSUMPTIONS:

1. Total building sewer length is approximately two times the total main sewer length.
2. Average building sewer diameter is 6 inches.
3. Average main sewer diameter is 12 inches.
4. Infiltration through the sewer joint is proportional to the diameter of the pipe.
5. The average ground water head on the building sewer is two feet (2 feet).
6. The average ground water head on the main sewer is five feet (5 feet).
7. Infiltration occurs at the joints, and the number of joints are assumed to be proportional to the length of the sewer line.

Infiltration, therefore, can be expressed by the following equation:

$$I \alpha D \sqrt{H}\ L \qquad \text{(equation 1)}$$

where:

I = Infiltration

D = Diameter of pipe

H = Ground water head on pipe

L = Length of pipe

I_B = Building sewer infiltration

Calculations:

$$I_T = I_B + I_M \qquad \text{(equation 2)}$$

I_T = Total infiltration

I_B = Infiltration from building sewer

I_M = Infiltration from main sewers

$I_B \alpha 6\sqrt{2}\ (2L)$ Substituting in equation 1 (Building sewer)

$I \alpha 12\sqrt{5}\ L$ Substituting in equation 1 (Main sewer lines)

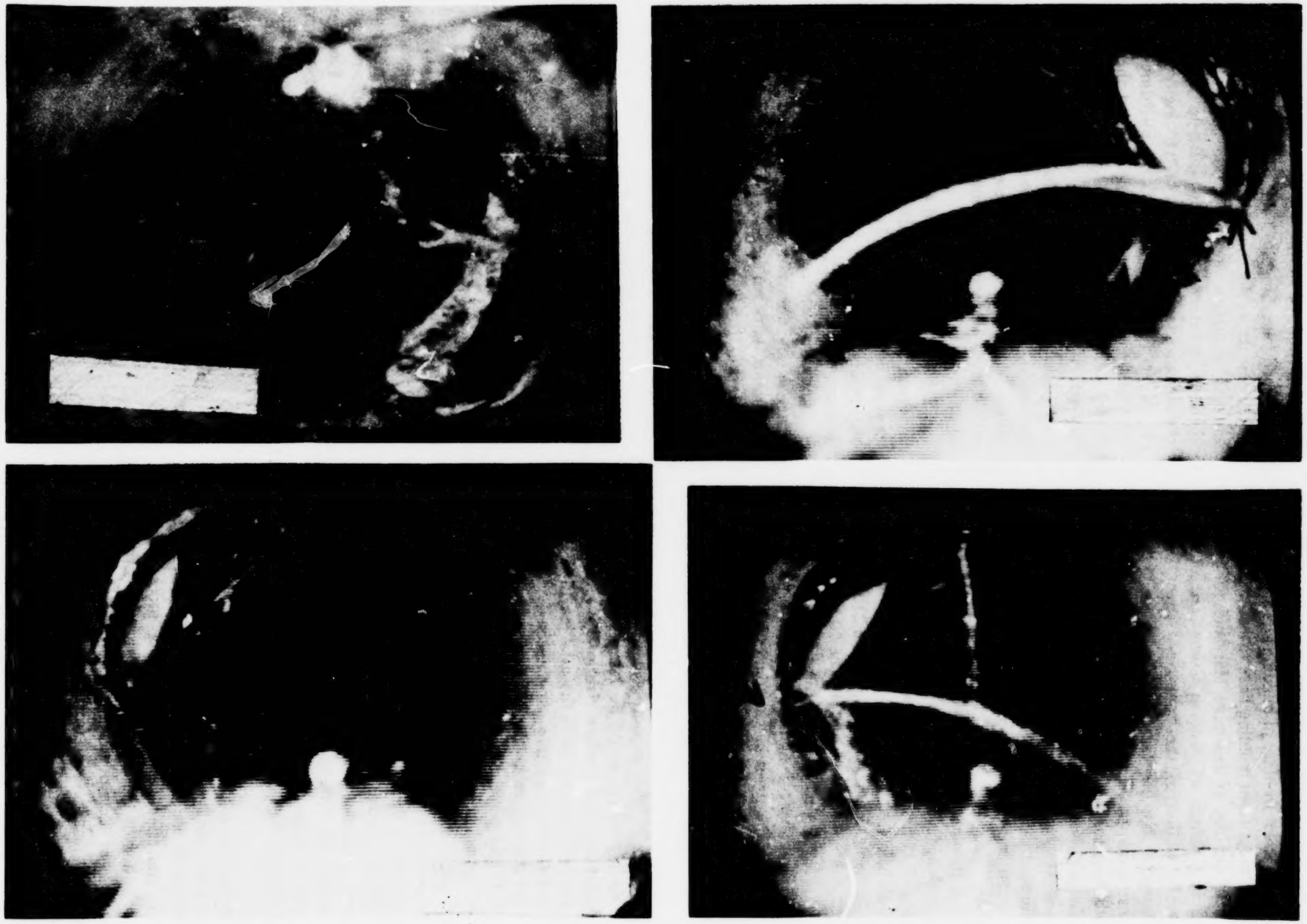
The relative amount of infiltration from building sewers is, therefore, estimated as follows:

$$I_B(\%) = \frac{I_B}{I_B + I_M} \times 100$$

$$I_B(\%) = \frac{6\sqrt{2}\ (2L)}{6\sqrt{2}\ (2L) + 12\sqrt{5}\ L} \times 100$$

$$I_B(\%) = 38\%$$

FIGURE 12



Courtesy: Underwater Tele-Equip., Ltd.

INFILTRATION AND INFLOW FROM BUILDING SEWER CONNECTIONS sewer system. The computed percentage will vary with the street frontage of building lots and the width of the street from building lines to street sewer lines.

In the City of Baltimore, Maryland, for example, the total length of building sewers connected to a specific section of the "old city" street sewer is influenced by the famous "row house" type of construction there. Long stretches of homes are built with common walls and no yard areas between the individual buildings, thus increasing the number of house connections per block. Significantly it was estimated in Baltimore that 75 percent of the total infiltration into the city sewers resulted from building sewers.

A theoretical computation of Baltimore building sewer length, in relation to street sewer length, was made for the row-houses section of Baltimore, as shown below.

Assume: House connection to be 25 feet long.
House frontages to be 20 feet wide.
A block length to be 500 feet.

The number of house connections for both sides of the street block would be 500 divided by 20, or 25, which multiplied by two equals 50.

The total length of building sewer lines would be 25 x 50, or 1,256 feet.

Therefore, the proportional total length of building sewers would be 1,256 divided by 550 (including cross street right-of-way), or about two and one half times the total length of street sewers into which they are connected.

This would make the building sewer infiltration potential 71 percent of the total infiltration into the sewer system, assuming that the infiltration rates are equivalent inasmuch as the quality of sewer pipe and joints are about the same. The row-house construction exists only in the older city and the percentage length of building sewers would be less in outlying areas where building lots have wider street frontages, although the length of the average building sewer would be increased for homes with a set-back from the property line.

Pipe and Joints for Building Sewers

The ability of building sewers to exclude infiltration water depends on the type of pipe used and the effectiveness of jointing procedures. In recognition of the importance of these materials, the surveys to determine jurisdictional sewer system practices made every effort to explore the policies and practices involving pipe and joints used for building sewers.

Investigations in the 26 representative systems laid open the broadly held opinion that recent developments in jointing materials have brought a marked reduction in infiltration attributable to building sewers. Jurisdiction officials and sewer contractors referred to the use of "O" ring-type joints as a great improvement in building sewer construction. Some jurisdictions reported they have undertaken programs to replace defective connecting sewers, including separation of foundation and basement drains, and roof leaders from these building conduits. The problems involved in excluding these inflow waters into building sewers, and thence into public sewer systems, are discussed in another section of this report.

Table 34, National Field Investigation – Summary of Permitted Pipe Materials and Joints in Building Sewers, lists the types of pipe and joints permitted in the 26 jurisdictions investigated in the national research project.

Consulting engineers were asked to list the pipe materials and joints that they specified to control infiltration into building sewers. The 66 replies are tabulated in Table 35, Consulting Engineers Survey – Pipe Material Specified for Building Sewers.

TABLE 35
CONSULTING ENGINEERS SURVEY PIPE MATERIAL SPECIFIED FOR BUILDING SEWERS

Vitrified Clay	**49**
Cast Iron	**44**
Asbestos Cement	**34**
Plastic	**18**
Bituminous Fiber	**4**
Concrete	**2**

Obviously some consultants specify more than one material and, in fact, more than one type of joint on the same pipe material. The listing on joint usage is contained in Table 36, Consulting Engineers Survey – Joints Specified for Building Sewers. Compression gaskets were listed as "O" Ring, Molded PVC, and Rubber Gasket.

TABLE 36
CONSULTING ENGINEERS SURVEY JOINTS SPECIFIED FOR BUILDING SEWERS

"O" Ring	**74**
Molded PVC	**32**
Rubber Gasket	**16**
Solvent Weld	**13**
Lead	**10**

TABLE 34
NATIONAL FIELD INVESTIGATIONS
SUMMARY OF PERMITTED PIPE MATERIALS AND JOINTS IN BUILDING SEWERS

City	Materials	Joints[1]
Baltimore, Maryland	Cast Iron	"O" Ring, Poured
	Vitrified Clay	"O" Ring
	Concrete	"O" Ring
Bloomington, Minnesota	Asbestos Cement	"O" Ring
	Cast Iron	"O" Ring, Lead
Dallas, Texas	Asbestos Cement	"O" Ring
	Cast Iron	Lead
	Vitrified Clay	"O" Ring
Denver, Colorado	Cast Iron	Neoprene, Slip Joint
	Vitrified Clay	Neoprene
	Concrete	Neoprene, Mortar
Ft. Lauderdale, Florida	Cast Iron	Rubber gasket, Lead
	Vitrified Clay	Rubber gasket, Plastisol
	Plastic	Chemical weld, Rubber gasket
Hot Springs, Arkansas	Bituminized Fiber	Slip type
	Cast Iron	"O" Ring, lead
	Vitrified Clay	ASTM C-425
	Concrete	"O" Ring
	Plastic	Chemical weld
Indianapolis, Indiana	Cast Iron	Mechanical
		ASTM C-425
Jacksonville, Florida	Cast Iron	Lead
	Vitrified Clay	Mastic, Wedgelock
Janesville, Wisconsin	Cast Iron	"O" Ring, Lead
Knoxville, Tennessee	Asbestos Cement	"O" Ring
	Bituminized Fibre	Friction
	Cast Iron	Lead
	Vitrified Clay	ASTM C-425
	Concrete	Rubber ring
Milwaukee, Wisconsin	Asbestos Cement	"O" Ring
	Cast Iron	"O" Ring, Lead
	Vitrified Clay	Cement, PVC, "O" Ring
	Concrete	Cement "O" Ring
Nassau County, N.Y.	Asbestos Cement	"O" Ring
	Cast Iron	Lead, Mechanical
	Vitrified Clay	Hot Asphalt, "O" Ring
New Orleans, Louisiana	Cast Iron	Lead, Compression gasket
New Providence, N.J.	Cast Iron	Poured lead
Oakland County, Michigan	Asbestos Cement	"O" Ring
	Cast Iron	–
	Vitrified Clay	–

[1] Type of joints is as listed by reporting agency.

TABLE 34 (Continued)

Omaha, Nebraska	Asbestos Cement	"O" Ring
	Cast Iron	Lead
	Vitrified Clay	Hot Asphalt, "O" Ring
Princeton, N.J.	Asbestos Cement	"O" Ring
	Vitrified Clay	"O" Ring
	Cast Iron	Lead
Richmond, Virginia	Cast Iron	Lead
	Vitrified Clay	–
	Cast Iron	–
San Jose, California	Asbestos Cement	"O" Ring
	Cast Iron	Lead, "O" Ring
Savannah, Georgia	Asbestos Cement	"O" Ring
	Cast Iron	Stainless collar
Suburban Sanitary Com., Washington, D.C.	Asbestos Cement	"O" Ring
	Cast Iron	Poured lead
	Concrete	"O" Ring
Toronto, Canada	Asbestos Cement	"O" Ring
	Vitrified Clay	"O" Ring
Washington, District of Columbia	Vitrified Clay	"O" Ring, Bituminous
	Cast Iron	Poured lead
Watsonville, California	Asbestos Cement	"Sleeve and Cement"
	Cast Iron	–
	Vitrified Clay	"O" Ring, Plastisol
Winnipeg, Canada	Asbestos Cement	"O" Ring
	Bituminized Fiber	
	Cast Iron	Caulked, Lead
	Vitrified Clay	Cement, "O" Ring
Yakima, Washington	Asbestos Cement	"O" Ring
	Cast Iron	Lead
	Vitrified Clay	"O" Ring
	Concrete	"O" Ring

Some of these jointing materials relate to particular pipes, and therefore their use would depend on the popularity of that pipe. In general the present selection of pipe and joints for building sewers closely parallels the usage for street and lateral sewers. Compression gaskets have improved the infiltration resistance of all types of pipe. However, cast iron pipe is in greater use in building sewers than in larger street sewers.

In the more extensive statistical survey of jurisdictions, the percentage distribution of pipe materials and joint usage was very similar to that specified by the consultants. Because of the larger sampling, however, a number of different materials such as wood and copper were reported. Table 37, National Statistical Survey – Building Sewer Pipe and Joint Materials Specified, lists the results according to regions and population groups.

The high incidence of cast iron again is shown in this national summary. The prevalence reflects not only the desire for strength and root resistance but also the fact that building sewers traditionally have been installed by plumbers using cast iron and poured joints for water lines and internal plumbing and soil pipes.

Proper choice of sewer pipe to minimize greatly or eliminate the large percentage of infiltration attributable to poorly constructed building sewers is becoming a more widely recognized need, as indicated in the above discussions and the statistical survey findings.

Bloomington, Minnesota, has demonstrated this

TABLE 37

NATIONAL STATISTICAL SURVEY
BUILDING SEWER PIPE AND JOINT MATERIALS SPECIFIED

		Pipe Materials											Joints						
Region	Population	Vitrified Clay	Asbestos Cement	Plastic	Cast Iron	Rein Concrete	Bituminous Fibre	Copper	Truss	Concrete	Wood Stave	Plastic	Bituminous	Mortar	Poured	Chem	Rubber Ring	Plastic	No Answer
East	Over 200,000	5	2	2	5	1	2	–	–	–	–	–	5	2	3	–	7	–	–
	100,000-199,999	6	2	–	5	–	1	–	–	–	–	–	2	3	4	–	7	–	–
	20,000- 99,999	15	7	3	18	–	2	1	–	–	–	–	4	5	11	–	19	2	1
	10,000- 19,999	4	2	1	4	–	1	–	1	1	–	–	2	1	3	–	4	1	1
	Under 10,000	1	–	–	1	–	–	–	–	–	–	–	–	–	1	–	1	–	–
Sub-Total		31	13	8	33	1	6	1	1	1	–	–	13	11	22	–	38	3	2
South	Over 200,000	5	1	–	4	–	–	–	–	2	–	–	1	1	2	–	5	1	–
	100,000-199,999	2	–	–	3	–	1	–	–	–	–	–	1	3	4	–	6	1	–
	20,000- 99,999	7	4	1	10	–	3	–	–	5	–	–	2	1	7	–	10	2	–
	10,000- 19,999	4	3	1	4	–	1	–	–	2	–	–	1	2	3	–	3	2	1
	Under 10,000	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sub-Total		18	8	2	21	–	5	–	–	9	–	–	5	7	16	–	24	6	1
Midwest	Over 200,000	4	–	–	4	–	–	–	–	–	–	–	–	1	2	–	2	3	–
	100,000-199,999	4	2	–	5	–	–	–	–	–	–	–	1	3	4	–	4	4	–
	20,000- 99,999	14	3	1	12	–	1	–	–	2	–	–	6	3	9	–	13	6	–
	10,000- 19,999	7	2	–	5	–	1	–	–	1	–	–	1	1	3	–	7	2	–
	Under 10,000	2	–	–	2	–	1	–	–	–	–	–	1	–	1	1	2	1	–
Sub-Total		31	7	1	28	–	3	–	–	3	–	–	9	8	19	1	28	16	–
Southwest	Over 200,000	6	4	–	6	–	–	–	–	–	–	2	3	2	5	–	5	5	–
	100,000-199,999	1	1	1	2	–	–	–	–	–	–	–	–	–	1	–	1	–	–
	20,000- 99,999	10	6	3	10	–	6	–	–	1	–	–	6	3	7	–	10	7	–
	10,000- 99,999	4	1	1	4	–	3	–	–	–	–	–	3	3	1	–	4	2	–
	Under 10,000	1	–	–	2	–	1	–	–	–	–	–	1	1	2	–	1	–	–
Sub-Total		22	12	5	25	–	10	–	–	1	–	2	13	9	16	–	21	14	–
West	Over 200,000	7	4	1	6	–	1	–	–	3	–	–	2	2	3	–	6	4	–
	100,000-199,999	7	4	1	6	–	1	–	–	2	–	–	–	2	1	1	7	3	–
	20,000- 99,999	27	17	–	22	–	7	–	–	4	–	–	5	8	9	–	26	12	–
	10,000- 19,999	9	9	–	9	–	–	–	–	3	1	1	–	2	4	–	11	4	–
	Under 10,000	2	2	–	2	–	1	–	–	–	–	–	1	1	–	–	2	1	–
Sub-Total		52	36	2	45	–	10	–	–	12	1	1	8	15	17	1	52	24	–
Canada	Over 200,000	2	–	–	2		–	–	–	–	–	–	–	2	2	–	2	–	–
	100,000-199,999	1	2	–	1	–	–	–	–	–	–	–	1	–	–	–	2	–	–
	20,000- 99,999	5	6	–	4	–	2	–	–	–	–	–	3	4	1	–	7	1	–
	10,000- 19,999	2	2	–	–	–	–	–	–	1	–	–	1	1	–	–	3	–	–
	Under 10,000	2	2	–	–	–	–	–	–		–	–	2	1	–	–	2	–	–
Sub-Total		12	12	–	7	–	2	–	–	1	–	–	7	8	3	–	16	1	–
Totals	Over 200,000	29	11	3	27	1	3	–	–	5	–	2	11	10	10	–	27	13	–
	100,000-199,999	21	11	2	22	–	3	–	–	2	–	–	5	11	14	1	27	8	–
	20,000- 99,999	78	43	8	76	–	21	1	–	12	–	–	26	24	44	–	85	30	1
	10,000- 19,999	30	19	3	26	–	6	–	1	8	1	1	8	10	14	–	32	11	2
	Under 10,000	8	4	–	7	–	3	–	–	–	–	–	5	3	4	1	8	2	–
Totals		166	88	16	158	1	36	1	1	27	1	3	55	57	92	2	179	64	3

concern by adopting specifications covering such building sewers. The criteria stipulate not only pipe materials but jointing practices and property line sewer stubbing procedures; these will, in the opinion of the city officials, minimize the role of building sewers as a major source of infiltration. Excerpts from these specifications are given in Table 38, Excerpts from Requirements for Building Sewers, Bloomington, Minnesota.

TABLE 38
EXCERPTS FROM REQUIREMENTS FOR BUILDING SEWERS BLOOMINGTON, MINNESOTA

I. Sewer Services
   A. Residential
      1. Materials
         a. Residential sewer services shall be of extra heavy spun cast iron pipe, not less than 4 inches in size, with a neoprene gasketed, or poured lead joint.
         b. Asbestos-cement pipe may be used only with open trench construction and granular bedding.
         c. Adaptors shall be used at property line sewer stub and shall be of a type approved by the Utility Supervisor or Water/Sewer Engineer.
   B. Commercial and Industrial
      1. Materials
         a. Vitrified clay pipe with a joint approved by the Utility Supervisor or Water/Sewer Engineer, or extra heavy cast iron pipe with neoprene gasketed or hot lead joints will be used.
         b. Asbestos-cement pipe may be used only with open trench construction and granular bedding.

The investigations of the 26 representative jurisdictions disclosed that many design engineers, municipal sewer officials, and contractors are concerned over the shearing action on building sewers at points where they cross the main street sewer trench. This shearing results from uneven settling in both lines, particularly where the street sewer is laid in an extremely deep trench and the building sewer is laid in a shallow trench.

Various types of construction have been proposed to counteract this condition. Where building sewers and street sewers meet at the same elevation, concrete encasement of the building sewer and some form of support for the "Y" connection may be used. When the main street sewer is laid in a deep trench and a drop connection must be provided for the building sewer, the entire riser may be encased in concrete, or at least the "T" connection at the main should be sleeved with concrete. The suggestions made during the course of the national investigations proved that the vital connection between building sewers and street sewers is receiving attention and that improved construction methods will be used in the future. These improvements will include greater attention to the backfilling and compaction of trenches.

When a new sewer is being constructed in an undeveloped area, it is common practice to "stub out" "Y's" and "T's" to allow for connection of building sewers between abutting properties. Specifications require that these fittings be properly plugged and caulked to prevent infiltration prior to the time they are used to connect building sewers to the street sewer. If these stub lines are improperly plugged, they can be the source of excessive amounts of ground water infiltration.

When old buildings are demolished and sewer connections are left unused, the connections should be plugged at the building line until linked to a new building – or totally eliminated if ~~no~~ new building connection is to be made. Unplugged old building connections were reported to be the source of as much infiltration flows as unplugged street sewer stubs.

Divided Authority Over Building Sewer Installation

Reference has been made to the impact of divided authority over building sewer installations, particularly on the effectiveness of construction and the consequent infiltration conditions. As part of the field investigations, emphasis was placed on the question of which local agencies maintain control over building sewers.

Of the 26 jurisdictions listed in Table 39, National Field Investigation - Summary of Specifications, Installation and Inspection Authority, 19 indicated that their building sewer installations were carried out exclusively under a split of responsibility between housing and plumbing officials and sewer officials. At Dallas, Texas, a single authority holds responsibility for the entire building sewer–not because a single local official covers the two separate segments of a building sewer but because a single agency, the water utility department, encompasses both plumbing and sewer functions. Three other jurisdictions reported similar total

TABLE 39
NATIONAL FIELD INVESTIGATIONS
SUMMARY OF SPECIFICATION, INSTALLATION AND INSPECTION AUTHORITY OVER BUILDING SEWERS

City	Type of Jurisdiction	Explanation
Baltimore, Maryland	Split Authority	As of 1968 building sewers from building to property line are specified, installed and inspected under the jurisdiction of the Department of Housing and Community Development. Plumbers licensed by the state lay the line from the building to the property line. "Drain Layers" licensed by the Department of Public Works lay the line from the property to the street sewer. The latter is inspected by the Department of Public Works. Permits are required for any connection to the street sewer.
Bloomington, Minnesota	Single Authority	Public Works Department has complete jurisdiction over building sewer connections on both private and public property.
Dallas, Texas	Single Authority	Water Utility Department has jurisdiction of public construction. Plumbing Inspector under this agency. Considerable interest in house connection problems. Department personnel make tap or connection to municipal sewer. Water test to property line.
Denver, Colorado	Single Authority	Chief waste water control engineer of the Waste Water Control Agency has full responsiblity for this activity.
District of Columbia, Washington	Split Authority	Engineering Division inspects sewers. Inspection Division inspects house connections. Completely separate operations.
Ft. Lauderdale, Florida	Split Authority	Building Department has jurisdiction on private property. City Engineer controls public right-of-way.
Hot Springs, Arkansas	Split Authority	Plumbing Inspector has jurisdiction over building sewer connections, but inspection is not performed.
Indianapolis, Indiana	Split Authority	Plumbing Inspector as a part of the building department has jurisdiction over building connections.
Jacksonville, Florida	Split Authority	Building Inspector is responsible for this activity on private land while the City Engineer exercises control over public part of connection on right-of-way or street.
Janesville, Wisconsin	Split Authority	Plumbing Inspector has jurisdiction from the building to the property line. The City Engineer has jurisdiction from the property line to the main sewer.

TABLE 39 (Continued)

City	Type of Jurisdiction	Explanation
Knoxville, Tennessee	Split Authority	Activity comes under plumbing code which specifies that plumber makes connection at property line. Plumbing Inspector is responsible for this connection. City Engineer is responsible for balance.
Milwaukee, Wisconsin	Split Authority	Plumbing Inspection Division of the Building Department has jurisdiction on private property. The City Engineer has jurisdiction over the portion on public property. The Building Department and Engineering Department coordinate their efforts in known "backwater problem" areas.
Nassau County, New York	Split Authority	County issues permit for the total connection. The County specifications cover connection from the main sewer to the "curb"line. Local building department issues permit from the "curb" line to the building. Inspection responsibility is divided the same way.
New Orleans, Louisiana	Single Authority	Sewerage and Water Board exercises complete jurisdiction over the building sewer and the Plumbing Department performs the work.
New Providence, New Jersey	Split Authority to some extent	Municipal engineer is in charge of sewer construction and house connections to within 5 feet of foundation of house.
Oakland County, Michigan	Split Authority	County Department of Public Works issues rules and regulations. Local unit of government provides any inspection and testing.
Princeton, New Jersey	Split Authority in some cases	Township and Borough are members of Sewer Operating Committee which maintains plants, lift stations, and main sewers. Township Engineer inspects construction in his area, SOC inspects in Borough and on trunks. SOC, Township Engineer, or Borough Engineer may all become involved in house connection inspections although house connections are not tested.
Richmond, Virginia	Split Authority	City Engineer has jurisdiction from the main sewer to the property line. The Plumbing Inspector (Department of Public Safety) has jurisdiction from property line to building.
San Jose, California	Split Authority	City Engineer has jurisdiction from the main sewer to the property line. The Plumbing Inspector (Building Department) has jurisdiction from property line to building.

TABLE 39 (Continued

City	Type of Jurisdiction	Explanation
Savannah, Georgia	Single Authority	Plumbing Inspector is only official charged with this activity.
Suburban Sanitary Commission, Washington, D. C.	Single Authority	Commission exercises complete control over sewer installation and all plumbing code activities.
Toronto, Canada	Split Authority	City Works Department has jurisdiction on public property. Plumbing Inspector has jurisdiction on private property.
Watsonville, California	Single Authority	City Engineer has jurisdiction on public property. Plumbing Inspector (Building Department) has jurisdiction on private property.
Winnipeg, Canada	Split Authority in some instances	In the Metropolitan Area most City Engineers have authority over building connections.
Yakima, Washington	Split Authority	Plumbing Inspector under the Planning and Community Development Department has jurisdiction over building connections.

control by a single agency. Another two indicated that split authority had been mitigated by joint actions.

In the case of Princeton, New Jersey, the problem of divided authority has been partially overcome by creation of a Sewer Operating Committee in which township and borough engineers hold membership. These engineering officials are involved in house connection inspections. At New Providence, New Jersey, the municipal engineer is responsible for sewer construction and house connections to within 5 feet of the building foundation wall.

The 212 jurisdictions covered in the national statistical survey also were asked how building sewers are regulated and who inspects them. Table 40, National Statistical Survey – How Building Sewers Are Regulated, indicates that 138 municipalities utilize plumbing codes for this purpose; sewer ordinances taking second place with 109 jurisdictions. The regional difference is small; in the East and in the West, ordinances are used more frequently than plumbing codes.

The same communities report that plumbing and building inspectors are used more for building sewer inspection than any other officials. Only in the East and West do the engineering inspectors approach or exceed the building or plumbing inspector in this function. Table 41, National Statistical Survey–Who Inspects Building Sewers?, summarizes the responses by region and population.

All of these survey results point to the fact that one of the most critical parts of the whole sewer system, the building sewer, receives the smallest and least coordinated attention. Laws and codes themselves are too often vague and, in truth, perhaps no agency is held responsible for some important aspect of infiltration and inflow control.

Advisory Committee Survey on Building Sewer Practices

Twenty-five separate jurisdictions represented on the Advisory Committee participated in the special survey on building sewer practices. Thirteen of the participants reported that the engineering or public works department specified the types of pipe material and joints used in these connecting lines, while nine indicated that the plumbing or building department bore this responsibility. Three reported that the responsibility was split between the two departments. As to inspection and testing of building sewers, the plumbing or building department was involved in 13 jurisdictions and the engineering department in seven, while responsibility for this operation was split in

TABLE 40
NATIONAL STATISTICAL SURVEY
HOW BUILDING SEWERS ARE REGULATED[1]

Question: Are House Sewer Connections Regulated — If so — By What?

Region	Population	Sewer Ordinance	Sewer Rules	Building Code	Plumbing Code
East	Over 200,000	3	4	4	4
	100,000-199,999	3	3	1	6
	20,000- 99,999	14	8	7	15
	10,000- 19,999	2	1	0	3
	Under 10,000	0	0	0	1
Sub-Total		22	16	12	29
South	Over 200,000	3	1	2	5
	100,000-199,999	2	1	1	2
	20,000- 99,999	5	4	3	11
	10,000- 19,999	1	0	0	3
	Under 10,000	0	0	0	0
Sub-Total		11	6	6	21
Midwest	Over 200,000	2	3	2	2
	100,000-199,999	2	0	1	3
	20,000- 99,999	10	4	5	13
	10,000- 19,999	4	1	0	5
	Under 10,000	1	0	1	1
Sub-Total		19	8	9	24
Southwest	Over 200,000	2	1	1	6
	100,000-199,999	1	0	0	1
	20,000- 99,999	5	2	4	6
	10,000- 19,999	2	0	3	3
	Under 10,000	2	0	0	0
Sub-Total		12	3	8	16
West	Over 200,000	3	2	1	6
	100,000-199,999	7	3	2	4
	20,000- 99,999	21	4	12	19
	10,000- 19,999	7	2	7	5
	Under 10,000	2	0	0	2
Sub-Total		40	11	22	36

[1] Many agencies gave more than one response.

TABLE 40 (Continued)

Region	Population	Sewer Ordinance	Sewer Rules	Building Code	Plumbing Code
Canada	Over 200,000	1	1	0	2
	100,000-199,999	2	1	0	1
	20,000- 99,999	1	1	1	6
	10,000- 19,999	0	1	1	2
	Under 10,000	1	1	1	1
Sub-Total		5	5	3	12
Totals	Over 200,000	14	12	10	25
	100,000-199,999	17	8	5	17
	20,000- 99,999	56	23	32	70
	10,000- 19,999	16	5	11	21
	Under 10,000	6	1	2	5
Total		109	49	60	138

five. One community reported that its public works department actually laid the entire house sewer to the foundation, thus maintaining complete control. Most jurisdictions reported that no testing of any consequence ever was made on building sewers.

Sixteen jurisdictions reported no difficulty in making sewer connections to the building sewers, while seven had experienced problems.

When asked if infiltration into building sewers was an important factor, 18 said "yes" and seven said "no." Four jurisdictions called particular attention to the role of the building sewer in conducting foundation drains into sewer systems. One member of the project Steering Committee made the following statement: "In my opinion, infiltration into building sewers is the most important factor in the overall problem. I estimate that the total footage of building sewers is four times that of the public sewer system for most communities. Where ground water tables are high and infiltration from ground water sources could be considered proportional to length of the street sewer and building sewer systems, then it is evident that leaks in public sewers cause about 20 percent of the problem and building sewers the remaining 80 percent." Another member of the committee said he did not feel that infiltration into building sewers in his area was a major problem, because of the tight specifications on materials. Obviously, there has been a great range of experience in this situation, much of which can be related to specific areas of the country and the age of the sewer system.

TABLE 41

NATIONAL MUNICIPAL STATISTICAL SURVEY
WHO INSPECTS BUILDING SEWERS?(1)

			Question: Is the Construction of House Sewer Connections Inspected – If so – By Whom?				
Region	Population	Inspector(2)	Building Inspector	Plumbing Agency	Sewer Department	Mun. Eng. Public Wks.	Dept. of Other
East	Over 200,000	3	6	3	2	3	0
	100,000-199,999	1	4	1	2	2	0
	20,000- 99,999	3	15	4	6	6	2
	10,000- 19,999	2	3	0	3	0	0
	Under 10,000	1	0	0	1	0	0
Sub-Total		10	28	8	14	11	2

TABLE 41 (Continued)

Region	Population	Inspector(2)	Building Inspector	Plumbing Agency	Sewer Department	Mun. Eng. Public Wks.	Dept. of Other
South	Over 200,000	0	5	1	0	1	0
	100,000-199,999	0	2	1	0	0	0
	10,000- 99,999	1	10	1	1	0	0
	Under 10,000	0	0	0	0	0	0
Sub-Total		1	21	3	1	1	0
Midwest	Over 200,000	1	2	2	0	2	0
	100,000-199,999	0	5	0	2	1	0
	20,000- 99,999	2	12	0	4	5	0
	10,000- 19,999	1	6	0	2	1	0
	Under 10,000	0	2	0	0	0	0
Sub Total		4	27	2	8	9	0
Southwest	Over 200,000	1	6	0	0	1	0
	100,000-199,999	1	2	0	0	0	0
	20,000- 99,999	3	8	0	0	0	0
	10,000- 19,999	2	3	0	0	0	0
	Under 10,000	1	2	0	0	0	0
Sub-Total		8	21	0	0	1	0
West	Over 200,000	0	5	2	2	2	1
	100,000-199,999	0	5	2	1	3	0
	20,000- 99,999	12	16	6	1	6	2
	10,000- 19,999	7	4	1	1	4	0
	Under 10,000	2	1	0	1	0	0
Sub-Total		21	31	19	6	15	3
Canada	Over 200,000	0	1	0	1	0	0
	100,000-199,999	0	1	0	1	0	0
	20,000- 99,999	1	4	1	1	1	0
	10,000- 19,999	0	0	0	0	3	0
	Under 10,000	0	2	0	2	0	0
Sub-Total		1	8	1	5	4	0
Totals	Over 200,000	5	25	8	5	9	1
	100,000-199,999	2	19	1	6	6	0
	20,000- 99,999	22	65	12	13	18	4
	10,000- 19,999	12	20	1	6	8	0
	Under 10,000	4	7	0	4	0	0
Total		45	136	24	34	41	5

(1) Many agencies gave more than one response.

(2) Not otherwise identified.

SECTION 8

ECONOMIC FACTORS IN INFILTRATION AND INFLOW CONTROL

The main responsibility of officials in the operation and maintenance of municipal public works facilities is to provide essential services and render urban living and life processes convenient, safe, and comfortable. Cost often is a forgotten factor – and is frequently of secondary importance when any failures or disruptions of services are experienced. The need to restore the operability of urban functions when they have been disrupted is paramount in the minds of the public and their public officials.

The effects of infiltration and inflow on the successful functioning of public sewer systems, pumping stations, and sewage treatment plants, and combined sewer overflow structures, frequently are viewed from the standpoint of physical conditions rather than of basic economic criteria. For example:

- When excessive sewer flows result in local street area flooding and inundation of private properties, the main task is to alleviate the surcharge effects, drain the flooded area and properties, and restore the area to clean condition. The question of cost is secondary.
- When sewage pumping stations and sewage treatment plants are by-passed, or operated at excessive loadings and reduced efficiencies, the major concern is the pollutional effects of the spilled untreated flows or the discharge of effluents of lowered quality. The fiscal factors are not considered.
- When combined sewer overflows are more frequent or last longer than usual, because of the intrusion of infiltration or inflow, today's concern centers on the degradation of the receiving waters, rather than on the cost of such pollution.

But these impacts of infiltration and inflow on collection, treatment, and disposal systems and receiving waters have economic implications even though the economic factors may be veiled. They must be weighed if jurisdiction officials are to evaluate the cost of overcoming the "Two I's" and compare the costs of permitting these conditions to continue with the benefits to be derived from corrective actions.

From investigations of representative jurisdictions and national statistical surveys, efforts were made to determine if some type of "price ticket" could be attached to the cost of infiltration and inflow, and the cost of control ascertained.

Economic Effects On Sewer Systems

The effects of infiltration and inflow on sewer systems have been outlined in Sections 2, 4, and 5 of this report. The findings of the various national investigations and surveys of practices and experiences in representative and statistical jurisdictions have been evaluated; they have been coupled with information obtained through inquiries to consulting engineers and state and provincial water pollution control agencies.

The research data are mainly related to physical rather than economic factors. The question must be asked: What are the economic impacts of infiltration and inflow on the vast network of sewers serving the United States and Canada?

The mileage of sewer systems constructed and in service in urban areas of the nation are staggering in their length and almost irreplaceable in their dollar value. Without dependable sewer service, the entire structure of urban residential, commercial, and industrial progress would fail.

According to a survey reported by the Water Industries and Engineering Services Division of the Business Defense Service Administration, U.S. Department of Commerce, 1,978.3 million feet of "residential sewer pipe" were in service in the United States by 1965, serving 140 million persons. The total sewer footage was to reach an estimated 2,942.4 million feet by 1970. It was predicted that an additional 1,240.4 million linear feet of sewers would be constructed in the decade between 1970 and 1980, to meet the needs of the growing urban complexes of America. By 1980, it was estimated, 3,732.8 million feet of residential sewer pipe would be in service, to handle the flow from 178 million urban residents.

Between 1964 and 1980, it was projected in another part of the Federal statistics, urban growth would require 2,198.8 million feet of 8-inch to 12-inch pipe; 214 million feet of 15- to 24-inch pipe, and 107.1 million feet of over 24-inch pipe, or a total of 2,520.5 million feet in coterminous United States. In addition, an estimated 649.1 million feet of sewer pipe will be required by 1980 to replace inadequate sewers now in service.

If excessive infiltration and avoidable inflow presently are usurping some 15 percent of this sewer capacity – an estimate that appears conservative on the basis of national data obtained during this project – it is evident that the equivalent of 440 million feet of sewers is now rendering this type of "pirated" service and handling flows of waste water that are "extraneous" under the terms of this study. In addition, on the basis of the 15 percent infiltration/inflow estimate, about 185 million linear feet of sewers might be saved in the future construction programs of municipalities if excessive infiltration and inflow could be eliminated.

It is conjectural whether or not the elimination of infiltration and inflow in the existing 2,942 million feet of sewers by rehabilitation methods could obviate some 15 percent of the vast construction burden of the 1970-1980 decade. However, some form of "price ticket" is applicable to this situation. Assuming the average cost of urban sewers of all sizes to be $15 per foot, the construction program for sewer installation between 1970 and 1980 will require the expenditure of $19 billion. Actually, the Business and Defense Services Administration's estimated cost for sewer construction for the period from 1964 to 1980 is $39 billion. If even 5 percent – or one-third of the assumed 15 percent infiltration impact – could be saved by improved control of infiltration and inflow, there could be a reduction of $1 to $2 billion in new sewer construction. The economic implication of infiltration and inflow control is obvious, even if the dollar data are only assumed.

A study of the needs of urban hydrology in the United States carried out by the American Society of Civil Engineers in 1969 under the sponsorship of the U. S. Geological Survey, Department of the Interior, reported the dollar value of sewer utilities now in service and the annual construction needs for sewage systems for the next several years. The data revealed that the replacement value of public sanitary sewers and treatment facilities is approximately $40 billion. Annual construction needs for sanitary sewers were estimated at approximately $1.5 billion, and storm sewers at about $2.5 billion.

The fiscal or economic motivation for correcting infiltration and inflow conditions is self-evident. The dollar value of extending the useful life of existing sewers and initiating better construction methods for the sewers of the future is augmented by the pollutional control benefits to be derived. The latter would represent an additional "profit" from the job of providing better sewers for anticipated national growth.

Economic Effects of Extraneous Water: Case Histories

Entry of extraneous waters into a separate sewer system, or construction of a separate sewer system with excessive allowances for infiltration and storm flow, can have a substantial effect on the economics of the system. Capital costs are increased by the need to provide excessive capacities in such a system. Maintenance and operation costs are increased by the need to collect, transport, pump, treat, and dispose of the excessive flows thus encountered.

When excessive infiltration and storm inflow occur in a system or are permitted by adopted engineering design criteria, the cost of construction of all portions of the systems is increased. In a study conducted for the Central Contra Costa Sanitary District in California, it was determined that an increase in infiltration and storm inflow allowances from 600 to 2,000 gallons per acre per day would increase by 33 percent the size of sewers required to serve a typical residential area. This amounted to 100 inch-feet of sewer per acre. The term "inch-foot" is the product of the sewer diameter in inches and its length in feet. At a cost of $1 per inch-foot, this would represent an increase of $100 for sewering one acre at the increased infiltration rate.

Costs would increase similarly for constructing trunk and interceptor sewers with capacities adequate for the excessive infiltration cited in the Contra Costa example. A trunk serving an area of 10,000 acres would cost approximately $100,000 per mile more if constructed with a capacity to handle the higher rather than the lower rate of infiltration – 2,000 gallons per acre per day rather than 600 gallons.

Presenting another example of the economic effect of excessive infiltration and storm inflow, a report prepared for a municipality in the Pacific Northwest stated:

"Because of the major effect that ground water infiltration and storm water inflow exert on the cost of the recommended long-range sewer system plans, it is worthwhile to discuss this effect as well as the available remedies. It was pointed out that peak wet-weather flows are on the order of seven to eight times the normal dry-weather flow of sewage alone. Since the existing system was not designed to convey or treat flows of this magnitude, the only available solution has been to by-pass flows untreated directly into the river. These by-passes have been in violation of the pollution control policy established by the sanitary authority.

"The problem can be corrected by (a) eliminating or reducing infiltration and inflow at the source; (b) collecting, conveying and treating the total waste stream including storm and ground water; or (c) a combination of the two methods. Since the major source of the trouble appears to stem from poorly constructed sewers laid below the ground water table, it is not likely that the source of the excess flow can be easily located or economically corrected. The alternative will require construction of a relief sewer along the north bank of the river to intercept and convey to the treatment plant those flows which are presently being by-passed untreated directly to the river. Further study will be necessary to determine the best solution to the excess flow problem.

"Insofar as the sewage treatment plant is concerned, this report assumes that the present condition of excess infiltration and inflow will remain uncorrected in the existing sewers, but will be largely prevented in new sewer construction. This means, very simply, that Stage 1 of the treatment plant expansion will be nearly twice as large as would otherwise be necessary, and that operating costs will be higher than would be necessary if excess flow could be eliminated.

"In view of the requirements of the sanitary authority that the sewer system must be brought into compliance with discharge requirements by 1970, it is unlikely any significant reduction in infiltration and inflow can be made in time to permit a reduction in the design capacity of the Stage 1 treatment plant. Any future flow reduction, however, will result in a deferment of the date when Stage 2 expansion must be undertaken. Since Stage 2 expansion of the plant represents an expenditure of $1.7 million in 1969 dollars, there is an obvious financial advantage to the city in correcting present infiltration problems."

Other economic situations are reported. Literature on them has been augmented by information obtained in the present national study of the inflow and infiltration problem. The investigator's report on interviews with city officials in Yakima, Washington, for example, contained this statement:

"The detrimental effect of excessive infiltration in this city can best be illustrated by the fact that an addition to the sewage plant, completed in 1965 at a cost of $1,230,000 would not have been necessary if infiltration had not been involved. Last year, 3,749 million gallons of sewage were treated at a cost of operation and maintenance, alone, of $99,051.30. Using a rate of 110 gallons per day per capita and a combined population of 55,000 – 48,000 in the city and 7,000 in the suburbs – the expected sewage flow would have been 2,190 million gallons, with a treatment cost of $57,837.90. Thus, it can be conservatively said that extraneous water in the sewer system is costing this city more than $41,000 per year."

In the case of Bloomington, Minnesota, which pays another authority for sewage treatment services, the public works director has estimated that each gallon per minute of extraneous water costs the city $100 per year.

A report prepared for Marin County, California, contains the following statement: "It is estimated that if storm water inflow in the Corte Madera and San Rafael watersheds could be reduced to a level similar to that found in well-constructed community systems, the cost of the recommended plan could be reduced $3 million below the $19 million estimated."

In a large metropolitan area in Australia, it has been estimated that it will cost in excess of $50 million to correct deficiencies in a major interceptor system. The deficiencies are described in a report on the system as follows:

"Insufficient sewer capacity for peak wet-weather flows is the primary deficiency in sewered areas and, at a local level, leads to a variety of undesirable effects such as backing up of sewage into house services and overflowing manholes. On a larger scale, the lack of capacity leads to overflows of sewage to watercourses in the harbor . . . flows in excess of calculated peak capacities often occur as a result of entrance of excessive amounts of storm water principally through illicit drainage connections or faulty pipe joints."

The $50 million cost cited above is only for correction of the interceptor sewer itself. Additional expenditures are necessary to correct the deficiencies associated with the trunk and collection system.

Winnipeg, Canada, reported it is constructing sewers at a cost of $15 million to provide relief of combined sewers from surcharged conditions occurring during wet-weather periods.

That the entrance of extraneous waters into sanitary sewer systems raises costs of maintenance and operation of treatment and pumping facilities is evidenced by data obtained through interviews in the national investigations, as described earlier in this report. Table 42, Cost of Treatment and Pumping of Infiltration and Inflow, is a summary of these interview-derived cost data from representative jurisdictions. Although 12 of the 21 agencies did not report any costs, primarily because of lack of information on infiltration and inflow volumes, the ones that did report them showed that substantial sums are expended for treating and pumping the extraneous water.

Sewer stoppages and cave-ins have been cited by

TABLE 42

NATIONAL FIELD INVESTIGATIONS COST OF TREATMENT AND PUMPING OF INFILTRATION AND INFLOW

Jurisdiction	Estimated Annual Cost[(a)] of Treatment and Pumping Infiltration	Inflow	Total
Watsonville, California	$19,009	$ 8,928	$27,937
Nassau County, New York	5,600	40,000	45,600
New Orleans, Louisiana	b	b	b
Bloomington, Minnesota	c	c	c
Yakima, Washington	NR	NR	NR
Province of Ontario, Canada	d	d	d
Jacksonville, Florida	e	e	e
Winnipeg, Canada	NR	NR	208 f
Baltimore, Maryland	g	g	g

a - Dollars per year unless otherwise noted

b - Pumping costs significantly increased; all flow pumped; 50% increase in cost during heavy rain

c - $100 per year for each 1 gpm of extraneous water

d - Earlier plant expansion, average cost of treating sewage times additional flows experienced during wet-weather

e - Treatment $130 per million gallons normally, $11 per million gallons pumping; increased flow causes increased expenses

f - Pumping only

g - Cost of of treatment Back River Plant – $37.59 per million gallons. At infiltration-inflow rate of 100 mgd, cost is $3,700 per day. No records of total hours of excess flows during any year.

NR - No report

most of the interviewees as one of the major economic effects.of excessive waters entering sewer systems. In Omaha, Nebraska, three full-time crews are maintained to clear stoppages and perform other emergency work. Clearing the stoppages costs an estimated $16 to $17 per joint.

San Jose, California, reported that corrective work on its sewer system cost $200,000 over a 10-year period, and that 40 percent of the maintenance cost was expended for emergencies, primarily on sewers. Numerous cave-ins, with an attendant average-cost of cave-in repair of $300, were reported in Jacksonville, Florida. At the time of the investigation interview, there were 180 known cave-ins awaiting or undergoing repair. That city is embarking on a program to replace approximately 130 miles of defective sewers at a cost of $15 million. Milwaukee, Wisconsin, reported that about $2 million per year is spent replacing old sewers and constructing relief sewers.

Of all the jurisdictions interviewed, corrective actions generally have been taken on a case-by-case basis. At New Orleans, Louisiana, corrective action on a problem basis is not economically feasible and a systems approach is necessary. This city stated that correcting the infiltration problem is invaluable and necessary, and that it is becoming increasingly important with implementation of the city's sewage treatment program. The Sewerage and Water Board has conducted a pilot correction program. The average unit cost to repair the sewer lateral was $2.25 per foot. In addition, it was found that all building sewers twenty years of age or older should be replaced at an estimasted cost of at least $2.82 per connection.

During the investigations of the 26 representative jurisdictions, very little information was obtained on the cost-benefit ratio of corrective actions to alleviate the problem of extraneous water in sewer systems. In one project undertaken in Bloomington, Minnesota, it is reported that corrective action costing $3,500 eliminated about 60 gpm of infiltration. The estimated annual savings resulting from this action were reported as $100 per gpm, or $6,000. The utility director of Ft. Lauderdale, Florida, said the corrective action program in effect there since 1957 has prevented overload conditions at the treatment plants.

In any sewer system, benefits to be achieved by eliminating or reducing infiltration and inflow into existing sewers must be evaluated against costs. The direct economic benefits to be obtained are readily ascertainable. To these must be added the less tangible benefits of public safety and convenience, which might be classified as hidden benefits further offsetting many of the hidden costs of infiltration and inflow.

Benefits Derived From Corrective Actions

What has already been stated in this section

TABLE 43

NATIONAL STATISTICAL SURVEY
HAVE BENEFICIAL RESULTS BEEN OBTAINED FROM CORRECTIVE ACTIONS?

Population	200,000+			100,000-199,999			20,000-99,999			10,000-19,999			Under 10,000			Totals		
Regions	Yes	No	NA	Yes	No	NA	Yes	No	NA	Yes	No	NA	Yes	No	NA	Yes	No	NA
East	5	–	4	4	2	1	8	3	12	1	1	3	–	–	1	18	6	21
South	7	–	1	4	2	–	4	1	5	1	–	3	–	–	–	16	3	9
Midwest	2	–	2	6	–	–	10	1	5	3	–	4	1	–	1	22	1	12
Southwest	4	–	3	1	–	1	7	1	2	2	–	2	–	–	2	14	1	10
West	6	0	1	5	1	2	12	2	16	5	–	6	1	0	2	29	3	27
Canada	2	1	1	–	–	2	4	–	6	1	–	2	1	–	1	8	1	12
Totals	26	1	12	20	5	6	45	8	46	13	1	20	3	0	7	107	15	91

demonstrates that the elimination of infiltration is desirable, and often necessary, to preserve the usefulness and service life of sewer systems, sewage pumping stations, and treatment plants. In addition, operation and maintenance of these facilities will benefit greatly from the elimination of ground waters that are "extraneous" to the basic function of these structures and therefore to be considered as intrusions pirating essential system capacities.

Accordingly, this project tried to ascertain the benefits derived from corrective actions taken by jurisdictions covered in the national investigation of the 26 representative jurisdictions plus the large number of systems covered by the national statistical survey. Such an economic weighing of costs versus benefits cannot be expected to provide specific "price tickets" on reduction in pollutional discharges that occur during (1) by-passing of raw or inadequately treated sewage at sewage pumping stations and treatment plants, (2) emergency spills at points in sanitary sewer systems, or (3) excessive overflows of storm waters from combined sewer regulator stations. Table 43, National Statistical Survey, Have Beneficial Results Been Obtained from Corrective Action?, presents data on the beneficial results of actions already undertaken by jurisdictions.

For the statistical jurisdictions responding in the United States and Canada, the vastly predominant opinion was that benefits have derived from infiltration correction projects. There were no marked variations of opinion among the different population groups. While in general a consensus existed for all sections, the Midwest and West provided the greatest number of affirmative opinions and the smallest percentages of negative ones.

For the entire survey, responses to this question showed 101 jurisdictions where benefits were achieved and only 10 where they were not.

It is important to note that these opinions on benefits derived from infiltration projects were not based on actual economic evaluations of costs versus benefits. An inquiry showed that 125 jurisdictions or more than 90 percent of those reporting, had made no economic analyses of infiltration correction; only about 8 percent had statistically evaluated the economic results. In the Midwest and Southwest, none of the replies indicated economic evaluations.

Data on costs and corrective measures were not accompanied by explanation of the methods used in this improvement work, except in one case where a dig-up job was listed as costing $200 and a sealing job as costing $3 per linear foot. Costs per linear foot were reported to range, in general, from $5 to $35 per linear foot. One project reportedly cost $70 per linear foot. Another jurisdiction cited a cost of only $0.15 per foot without any explanation of the method utilized. Another respondent said the cost of infiltration control was the same as for new construction. This may be interpreted as referring to a physical replacement of defective sewer lines. Because of the undue range in reported costs of correcting infiltration, any firm computation of average national experience is precluded; but a general cost in the area of $5 to $20 per foot might be estimated.

One reply said a manhole job cost $2,000.

Another reply gave the cost of sealing 44 leaks as $5,909. Still another jurisdiction reported an expenditure of $50,000 for infiltration correction, apparently by means of sewer replacement and repair, at a unit cost of $20 per linear foot.

In a majority of cases, resoonding jurisdictions reported no cost data. The number not replying cannot be disregarded. It leads to the conclusion that more public officials should give further attention to this important operation and maintenance phase of sewer system management and administration.

It is obvious, from the broad spread of cost figures provided, that methods used for infiltration correction may have varied widely. At any rate, it would be inadvisable to use survey information as a basis for any firm conclusions on cost of infiltration correction. However, the dearth of information and the lack of any uniformity in cost figures cannot alter the estimate of $15 per linear foot of sewer construction. This estimate, used earlier in this section to ascertain the economic effect of infiltration on future sewer construction programs, seems justified in the light of even the scattered cost data disclosed by the survey.

The preponderance of opinions that infiltration control is beneficial economically must be classed as a specific finding of the survey, even though this consensus was not supported by meaningful economic analyses of the nature sought by the national statistical survey. Requirements for tertiary treatment of wastewater treatment plant effluents at a cost up to $0.30 per 1,000 gallons will tend to make infiltration and inflow control an economic necessity.

Plans for Future Corrective Actions

As stated earlier in this report, the national statistical survey attempted to ascertain whether or not jurisdictions in the United States and Canada intend to carry out pre-corrective surveys of infiltration conditions in their sewer systems; whether such surveys will be followed by actual corrective actions, where needed or indicated, and whether budgetary funds have been, or will be, allocated for such work.

The survey endeavored to ascertain if the plans for corrective action were nebulous, actually backed up by budgetary appropriations for current expenditures, or for a five-year program. Survey responses were highly variable, and not definitive enough to warrant specific interpretation. However, it is apparent that in a number of jurisdictions actual funding for infiltration correction is a reality.

In the over-200,000 population class, one corrective program was reported to involve the expenditure of $500,000 per year. Another jurisdiction reported budgeting for $200,000 to $750,000 worth of construction work to overcome excessive infiltration. Still another jurisdiction indicated that it planned to spend from $150,000 to $500,000. In another case, planned work will cost from $300,000 to $1,000,000. The large extent of such work in the over-200,000 population category indicates infiltration control now is a valid and recognized facet of sewer maintenance programs in the larger municipalities of the United States and Canada.

In the jurisdictions with populations of 100,000 to 200,000, more limited budgeting was reported, ranging from $10,000 to $250,000. In the under-10,000 group, low-budgeted cost figures were reported. In the 10,000- to 20,000-class, minor expenditures of $5,000, $23,500, $10,000, $40,000, and $50,000 were cited as contemplated for current or five-year programs. In the 10,000-20,000 population class in Canada, the highest expenditure reported from respondent jurisdictions was $50,000.

The data obtained by the statistical survey admittedly are sparse. However, one finding does stand out as a result of the national statistical survey: Many jurisdictions are planning surveys and corrective actions, and validating these intentions by the specificity of their plans to allocate and expend budgeted sums of money for this purpose. Admittedly, this is not a universal trend, but it is widespread enough to stimulate other communities to embark on positive planning and allocations of funds for infiltration surveys and infiltration corrective actions.

SECTION 9

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The American Public Works Association is deeply indebted to the following persons and their organizations for the services they rendered to the APWA Research Foundation in carrying out this study for the local governmental jurisdictions and the Environmental Protection Agency who co-sponsored the study. Without their cooperation and assistance the study would not have been possible. The cooperation of the American Society of Civil Engineering (ASCE) and the Water Pollution Control Federation (WPCF) is acknowledged for their participation on the project Steering Committee.

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SECTION 10

GLOSSARY OF PERTINENT TERMS

Area way–A covered or uncovered platform on paved entrance to a grade or below grade entrance of a building, usually equipped with a drain to remove precipitation runoff water.

Building Sewer–The conduit which connects building waste water sources to the public or street sewer, including lines serving homes, public buildings, commercial establishments, and industrial structures. In this report, the building sewer is referred to in two sections: (1) The section between the building line and the property line, frequently specified and supervised by plumbing or housing officials; (2) the section between the property line and the street sewer, including the connection thereto, frequently specified and supervised by sewer, public works, or engineering officials. (Referred to, also, as house sewer and building connection.)

By-pass–A pipe line which diverts waste water flows away from or around, pumping or treatment facilities – or by-passes them–in order to limit the flows delivered to such facilities and prevent surcharging or adversely affecting their operation or performance.

Cellar Drain–A pipe or series of pipes which collects waste waters that leak, seep, or flow into subgrade parts of structures and discharges them into a building sewer or disposes of them by other means in sanitary, combined or storm sewers. (Referred to, also, as "basement drain.")

"Clean Waters"–Waste waters from commercial or industrial operations that are uncontaminated; do not need, and could not benefit from, waste water treatment processes, and for sanitary purposes do not require disposal into public sewers, particularly separate sanitary sewers.

Collector Sewer–A sewer located in the public way which collects the waste waters discharged through building sewers and conducts such flows to larger interceptor sewers and pumping and treatment works. (Referred to, also, as "Street Sewer.")

Combined Sewer–A pipe or conduit which collects and carries sanitary sewage with its component commercial and industrial wastes and infiltration and inflow waters at all times, and which, in addition, serves as the collector and conveyor of storm water runoff flows from street and other sources during precipitation and thaw periods, thus handling in a "combined" way all these types of waste waters.

Exfiltration–The leakage or discharge of sewer flows into the ground through pipes, joints, manholes, or other sewer system structures; the reverse of "infiltration."

Foundation Drain–A pipe or series of pipes which collects ground water from the foundation or footing of structures and discharges these waters into sanitary, combined, or storm sewers, or to other points of disposal, for the purpose of draining unwanted waters away from such structures.

Ground Water Table–The top elevation of the ground water contained in the soil, as it varies from season to season or from time to time because of precipitation and drainage conditions. Immersion of sewer pipe in ground water, partially or completely under the ground water table, causes infiltration, through the natural phenomenon of water seeking its lowest level.

Infiltration–The discharge of ground water into sewers, through defects in pipe lines, joints, manholes or other sewer structures.

Inflow–The discharge of any kind of water into sewer lines from such sources as roof leaders, cellar and yard-area drains, foundation drains, commercial and industrial so-called "clean water" discharges, drains from springs and swampy areas, etc. It does not include "infiltration" and is distinguished from such waste water discharges, as previously defined.

Infiltration/Inflow–A combination of infiltration and inflow waste water volumes in sewer lines that permits no distinction between the two basic sources and has the same effect of usurping the capacities of sewer systems and other sewer system facilities.

Infiltration Allowances–The amount of infiltration that is anticipated in sewer systems, considered inevitable under sewer construction and sewer service conditions, and authorized and provided for in sewer system capacity design and in sewer construction practice. A distinction is made between "sewer design infiltration allowances" which the designer provides for in-structuring the total sewer system, and "construction infiltration allowances" permitted in the specifications covering the construction of specific projects and specific sections of the total sewer system.

Interceptor Sewer A sewer which receives the flow from collector sewers and conveys the wastewaters to treatment facilities.

Joints—The means of connecting sectional lengths of sewer pipe into a continuous sewer line, using various types of jointing materials with various types of pipe formations which make possible the jointing of the sections of pipe. The number of joints depends on the lengths of the pipe sections used in the specific sewer construction work.

Jurisdiction—Any governmental entity, such as city, town, village, county, sewer district, sanitary district or authority, or other multi-community agency, which is responsible for and operates sewer systems, pumping facilities, regulator-overflow structures, and waste water treatment works.

Overflow—A pipe line or conduit device, together with an outlet pipe, that provides for the discharge of portions of combined sewer flows into receiving waters or other points of disposal, after a regulator device has allowed the portion of the flow which can be handled by interceptor sewer lines and pumping and treatment facilities to be carried by and to such water pollution control structures.

Pipe Sealing—A method of correcting leaks or defects that cause infiltration of excessive extraneous waters into sewers using physical or chemical materials, applied by interior or exterior means, and sealing such points or defects so that the infiltration waters are reduced or eliminated.

Pipe Tests—Various methods for testing sewer lines (after construction and in service) to ascertain whether or not infiltration allowances have been met, and locating the sources of infiltration that exceed construction specifications. Such tests include infiltration tests, exfiltration tests, air tests, and such means as smoke bomb tests to locate sources of infiltration in new and existing sewer lines.

Precipitation—Rainfall or thawing snow and ice that produce storm water runoff from streets, roads, and other impervious surfaces; percolate into the soil and augment the ground water; are held in the interstices of the soil; produce inflow into sewer systems, or affect the ground water table.

Regulator—A device or apparatus for controlling the quantity of admixtures of sewage and storm water admitted from a combined sewer collector line into an interceptor sewer, or pumping or treatment facilities, thereby determining the amount and quality of the flows discharged through an overflow device to receiving waters or other points of disposal.

Roof Leader—A drain or pipe that conducts storm water downward from the roof of a structure and then into a sewer for removal from the property, or onto or into the ground for runoff or seepage disposal.

Roots—Fine or capillary root formations from trees that enter sewer lines, primarily sanitary sewers, in search for water and cause clogging of these conduits as the roots grow in length and volume. In the context of this report, the significance of root formations in sewers is that they enter into sewer lines through the same pipe and joint defects as those which permit infiltration or exfiltration to occur.

Sewer Inspection—Methods for determining the condition of new or existing sewer systems (in terms of infiltration conditions) by visual inspection, closed-circuit television viewing, photographic methods, or other means.

Sewer-Use Ordinance—A regulation, code, or ordinance enacted by a jurisdiction to specify the types and volumes of waste waters that can be discharged into sewer systems, the waste waters that cannot be so discharged, and the fees or charges to be imposed for the privilege of discharging those wastes and volumes which are permitted.

State and Provincial Water Pollution Control Agency—A branch of the government which imposes and enforces water quality standards, establishes standards of design for sewer systems and pumping and treatment facilities, and has responsibility for maintaining established water pollution control standards in receiving waters.

The "Two I's"—A phrase adopted for this report, to designate the two factors of infiltration and inflow which affect sewer systems and the other waste water handling facilities evaluated in this project and report.

SECTION 11

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As a part of the Project, a bibliography was developed. Entries have been limited to references which give information pertinent to control of infiltration and inflow. Articles without technical information are not included. Author and subject indices are provided. Bibliography items are not listed in any order, but are identified by a serial number.

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Sewage and Industrial Wastes, vol 27, no 3; pp 245-254; discussion pp 254-56, March 1955

Descriptors: Control Practice, Infiltration Tests, Joints

Experience with sewer joints and leakage. How infiltration on sanitary sewers can be kept to reasonable minimum. Tests proved that it is possible to obtain acceptable joints with rubber ring joints on concrete and asbestos cement pipe and with hot-poured joints on vitrified tile.

017 CLAY PIPE ENGINEERING MANUAL

Clay Sewer Pipe Association, Incorporated, Columbus, Ohio

Descriptors: Bedding, Construction Procedures, Design

Data on design, and construction of sewer layout, storm sewers and sewer pipe and drains.

018 CORRECTING STORMWATER AND INFILTRATION, TONAWANDA, NEW YORK

N. L. Nussbaumer
Sewage and Industrial Wastes, vol 28, no 8; pp 977-982, August 1950

Descriptors: Combined Sewers, Storm Sewers

Design of drainage projects based on system of storm sewers deep enough to intercept surcharged storm flow from sanitary sewers, and connected to existing storm sewer outlets.

019 NEW DATA ON SEWER INFILTRATION – EXFILTRATION RATIOS

S. Barland
Public Works, vol 87, no 9; pp 97-98, September 1956

Descriptors: Exfiltration, Infiltration Tests, Pressure Tests

Recent findings ... on unfiltered water in sewer lines give help in evaluating testing data: infiltration test, exfiltration or internal pressure tests, further tests to ascertain if proportionate ratio might exist between infiltration and exfiltration in testing.

020 INFILTRATION MEASUREMENTS IN SEWERS OF SMALL SIZE

R. A. Lincoln
American Society of Civil Engineers – proc: (Journal of Sanitary Engineering Div.), vol 83, no SA2, paper no 1203; 9 pp

Descriptors: Infiltration, Sutro Weirs

Rapid and accurate method of measuring groundwater infiltration flows on newly constructed sanitary sewers of small size.

021 STUDY OF RESISTANCE OF SEWER PIPE JOINTING MATERIAL TO ENTRY OF TREE ROOTS

C. E. Keefer
Water and Sewage Works, vol 104, no 3; pp 128-129, March 1957

Descriptors: Roots, Joints

Joints made of mixture of clay and rock salt do not prevent entry of tree roots. Tests with CPO-2 bitumastic compound were not entirely successful; there were no roots in any of cement joints, copper joints, G-K compound joints (including those) that had been previously primed with G-K primer.

022 SMALL-SIZE PIPE FOR SANITARY LATERAL SEWER

Building Research Advisory Board, Federal Housing Administration, contract no Ha-fh-646; February 28, 1957
Building Research Institute: Washington, D.C., May 1957

Descriptors: Design

The problem can be stated in the form of three questions: 1) What is the acceptable minimum size pipe... in street sanitary sewers in residential areas? 2) What conditions should be attached...? 3) What appropriate recommendations should be made with good design, construction and maintenance practices...?

023 VARIATION OF SEWAGE FLOW IN COLLEGE TOWN

G. D. Hutchinson; E. R. Baumann
Sewage and Industrial Wastes, vol 30, no 2; pp 157-163, February 1958

Descriptors: Flow Measurement, Sanitary Sewer

Sewage flow study was made of City of Ames, Iowa with population of 27,000; study demonstrates need for nationwide seepage flow study in cities of various sizes; study indicates that week's study of hourly flow variation might portray sewage flow as well as year's study.

024 DESIGN AND CONSTRUCTION OF SANITARY AND STORM SEWERS

American Society of Civil Engineers and Water Pollution Control Federation, New York, 1969. (ASCE Manual of Engineering Practice No. 37, WPCF Manual of Practice No.9.)

Descriptors: Construction, Design

Manual of recommended practice.

025 VITRIFIED CLAY PIPE ENGINEERS' HANDBOOK

Southern Clay Pipe Institute, Atlanta, Georgia, 1960

Descriptors: Clay Pipe, Design, Installation, Sanitary Sewers

...manual on the use and installation of clay pipe and.... products.... to those engaged in the design and construction of sewerage systems, drains and others.

026 EXPERIENCE WITH PRECAST SEWER JOINTS

T. R. Murray
Public Works, vol 93, no 9; pp 131-132, September 1962

Descriptors: Joints, Tests

Infiltration tests by constructing circular diaphragm or bulkhead with 2-inch pipe through center and installing diaphragm at downstream end of sewer using expansible rubber gasket around perimeter to secure watertight seal in pipe; tests showed that precast joints and continuous granular bedding represent substantial improvement in underground pipe line design.

027 CONCRETE PIPE FIELD MANUAL

H. F. Peckworth
American Concrete Pipe Association; Chicago, 1962, catalogue no 666.993 Z621

Descriptors: Concrete Pipe, Design, Installation, Sanitary Sewers, Storm Sewers

Sanitary sewer pipe, culverts, pressure water pipe drain tile and storm sewer; factors affecting strength; sanitary sewer design data; design of storm sewers and culverts, plus information relating to all of the above.

028 ESTIMATION OF DESIGN MAXIMUM DOMESTIC SEWAGE FLOW RATES

J. J. Leute
Sanitary & Municipal Engineering, John Hopkins University, order no 64-365; vol. 202 pp 925, 1963

Descriptors: Design, Flow Measurements

While hydraulic design procedures for sanitary sewerage systems are usually straightforward, determination of the flows for which design is to be carried out is often done by application of unprecise rules of thumb. The results from up to two years of continuous sewer gaugings from seven study areas in four cities in the .... U.S. are used to develop a method for estimating the qualities of flow due separately to domestic sewage, to *infiltration* and to *exfiltration*. .... a method is developed.... to estimate the maximum rate of domestic sewage flow.... during a selected design period. The reliability is studied... and techniques are shown whereby the... estimate may be adjusted... to allow for uncertainty. An illustrative example is shown....

029 LOW PRESSURE AIR TEST FOR SANITARY SEWERS

R. E. Ramseier, G. C. Riek
ASCE-proc. (Journal of Sanitary Engineering Div.) vol 90, no SA2; pt 2, paper 3883; pp 1-29, April 1964

Descriptors: Air Testing, Clay Pipe, Tests

Effect of moisture on permeability of vitrified clay sewer pipe and its effects on testing procedure; ...field tests show that pipe without detectable failure will lose less than 0.003 cubic feet of air/min/sq ft of internal pipe surface and that any air loss exceeding 2 cuft/min can be located.

030 THE INFILTRATION OF GROUND WATER INTO SOIL SEWERS

D. R. Smith, J. A. Clifford
The Chartered Municipal Engineer, vol 90, pp 169-175, June 1963

Descriptors: Economics, Flow Measurements, Ground Water, Infiltration, Surcharge

A result of three years of investigation into infiltration, its causes and effects. Flow measurements, economics and remedial measures are discussed.

032 SURVEY OF EXPANSION JOINTS FOR PIPEWORK SYSTEMS

M. Neal
Engineering Materials and Design, vol 8, no 3; pp 168-175, March 1965; vol 8, no 4; pp 240-245, April 1965

Descriptors: Joints

Respective advantages of rubber expansion joints, slip joints, and various forms of bellows joint and surveys units currently available.

031 SEWER DESIGN – INFILTRATION DETECTION AND CORRECTION

B. J. Haney
L.S.U. – Engineering Research Station, bulletin 83, pp 55-71, 1965

Descriptors: Design, Infiltration

Calculation of capacity of sewer system sizing of pipe, determination of pipe slope, selection of pipe material, and proper installation of pipe as basic steps in design of gravity sewer system.

033 MUNICIPAL REQUIREMENTS FOR SEWER INFILTRATION

Public Works, pp 158-162, June 1965

Descriptors: Design, Infiltration

Feedback of a questionnaire filled out by municipalities. Questions deal with what infiltration equation did each community use.

034 WATERTIGHT SEWER BUILT UNDER DIFFICULT CONDITIONS

R. Pelishek
Public Works, p 84, September 1965

Descriptors: Construction, Joints

Description of rubber joint gaskets used in difficult soil and water conditions.

035 UNDERGROUND DRAINAGE AND SEWER PIPES IN THIN RIGID PVC

British Plastics, vol 39, no 10; pp 577-578, October 1966

Descriptors: Joints, Plastic Pipes

Use of rubber ring sealed socket-joint for pipe connection; testing...; advantages... even... when dealing with aggressive sewage, soils....

036 SOIL CHEMICAL CHANGES AND INFILTRATION RATE REDUCTION UNDER SEWAGE SPREADING

R. E. Thomas, W. A. Schwartz, T. W. Bendixen
Soil Science Society of America, proc., vol 30, no 5; pp 641-646, Sept.-Oct. 1966

Descriptors: Infiltration, Soils

Laboratory and field lysimeters were used to investigate site and nature of soil-pore clogging under sewage spreading; site of clogging was located by determining with sewage meter impedance profile at 0.5 cm depth intervals; soil samples were analyzed for sulfide, iron, phosphate, total organic matter, polysaccharide, and polyuromide to evaluate possible causative relationships.

037 CONCRETE PIPES — REVIEW OF RECENT DEVELOPMENTS IN GREAT BRITAIN AND SOME PROBLEMS ENCOUNTERED

N.W.B. Clarke
International Congress of Precast Concrete Industry, 5th proc.; pp 117-124 May 21-26, 1966

Descriptors: Concrete Pipe

Problems encountered and experience obtained in design of rigid underground pipes in Great Britain during past 10 years are reviewed, particularly regarding flexible joints, pipe beddings, site work and impact factors; comparative impact and bedding factors are shown in tables.

038 AN EVALUATION OF THE PROBLEMS OF SANITARY SEWER DESIGN

J. C. Geyer, J. J. Lentz
Water Pollution Control Federation, vol 38, no 7; p 1138, July 1966

Descriptors: Design, Sanitary Sewers

General problems facing sewer designers have been studied using field data collected in four United States communities. Analysis of these data indicates that basic causes of maintenance difficulties are tree roots, accumulations of debris in the absence of roots, other causes, and in areas having cohesionless sub-soil, sewer cave-ins. Proportionately fewer blockages occur when grades are moderate, and proportionately more occur at the upper terminals of the sewers. In 8-inch pipe, manhole spacing has little effect on the labor costs of stoppage relief. Emphasis is placed on statistical techniques for estimating domestic sewage flow. Flow of rainwater and groundwater was at times found to be excessive in all systems studied. Limited data on costs of operating and maintaining sewage pumping stations are reported and evaluated.

039 PIPE JOINT BAFFLES ROOTS IN FIVE YEAR TEST

Public Works, p 130, July 1966

Descriptors: Concrete Pipe, Joints

U. S. Concrete Pipe Co. laid a 4-inch vitrified clay line to test for root intrusion. The results were very favorable to the pipe.

040 DESIGN CONSIDERATIONS FOR SEWER PIPES MADE FROM RIGID MATERIALS

K. E. Seal, M. V. Mountford
New Zealand Engineering, vol 23, no 3, pp 280-298, July 1968

Descriptors: Asbestos-Cement Pipe, Clay Pipe, Concrete Pipe, Design, Joints

A detailed mathematical analysis of pipe stresses and strength when laid in ground. Discusses joints, bedding and various types of failure.

041 PIPE JOINTS LIMIT INFILTRATION

G. W. Clark, Jr., M. L. Leyrer
Civil Engineering, New York, vol 37, no 1; pp 62-63, January 1967

Descriptors: Groundwater, Joints

City engineers in Muskegon, Michigan designed sanitary sewer trunk that would be placed in area having high water table; limiting infiltration was most important.

042 INFILTRATION AND SEWER FOUNDATIONS

T. W. MacDonald, J. K. Mayer, S. E. Steimle
Public Works, vol 98, no 12; pp 105-107, December 1967

Descriptors: Bedding, Foundation

Study was initiated to determine most suitable foundation materials and best types of sewer arrangements, under various conditions, which will effectively decrease and control infiltration in Gulf Coast area, and to test various foundation materials and arrangements in combination with various laying conditions in order to determine most suitable bedding in number of soil types common to area.

043 LOW PRESSURE AIR TESTING OF SEWERS

T. P. Schacher
Public Works, pp 103-104, 150, December 1967

Descriptors: Air Testing

A mathematical but practical approach using Boyle's Law.

044 WHEN SHOULD NEW SEWERS BE PHOTOGRAPHED?

R. E. Falardeau
Public Works, p 148, April 1968

Descriptors: Construction, Photography

Writer feels new sewers should be inspected by photography as soon after construction as possible.

045 EXFILTRATION TESTING OF LARGE SEWERS IN KANSAS CITY, MISSOURI

J. F. Nadung, L. W. Weller
Water and Wastes Engineering, vol 4, no 9; pp 87-89, September 1967

Descriptors: Concrete Pipe, Exfiltration Test

Test results discussed are for sewers constructed of reinforced concrete pipe, with manholes included in test sections; exfiltration specification used permits (a certain) leakage; data are presented...; exfiltration test-conditions and results are summarized.

046 PUT INTERCEPTOR ON LAKE BOTTOM

American City, vol 83, no 9; pp 129-130, September 1968

Descriptors: Interceptor, Joints

Design and method of placing of unusual interceptor sewer around scenic Lake Sammamish in Metropolitan Seattle, Washington; method avoids trench excavation; sewer is submerged, lying on lake bottom; *special bottle-tight joints* make this possible, unusual feature of interceptor is design of its access manholes, portable aluminum shaft that can be lowered to seat on sealed, submerged manhole....

047 HOW TO ESTIMATE STORM WATER QUANTITIES

H. M. Gifft, G. E. Symons
Water and Wastes Engineering, vol 5, no 3; pp 46-50, March 1968

Descriptors: Design, Runoff

Several factors involved in determining quantities of storm water are discussed for storm sewer design as related to rainfall and runoff; derivation of formulas for calculation of drainage area shape, rainfall intensity – frequency date, time of concentration and coefficient of runoff; nomograph for determining... time of flow.

048 AIR TESTING SEWERS

S. H. Hobbs, L. G. Cherne
Journal of the Water Pollution Control Federation, vol 40, no 4; p 636, March 1968

Descriptors: Air Testing

For location of leakage and control of infiltration or exfiltration. Bloomington, Minnesota, sewers were checked with the air testing methods which were stated to be faster and more economical... used in construction, sewer service, and repair...

049 RUNOFF ESTIMATES BASED ON INFILTRATION CAPACITY, ANTECEDENT MOISTURE CONDITIONS AND PRECIPITATION

R. G. Andrews
Agricultural Engineering, vol 31, no 1, pp 26-28, January 1950

Descriptors: Rainfall, Runoff, Soils

A discussion of a method for estimating runoff based on the infiltration method. Infiltration capacity is defined as the rate at which infiltration would take place at any instant were the supply to equal or exceed this capacity.

050 EXPERIENCE AND RESEARCH WITH ASBESTOS-CEMENT PIPES BURIED IN VICTORIAN CLAYS

J. E. Holland, G. Kassaff
Asian Regional Conference on Soil Mechanics and Foundation Engineering, 3rd proc., vol 1; pp 94-98, September 25-28, 1967

Descriptors: Asbestos Cement Pipe, Clay Soils

In some of expansive-clay areas of Victoria, Australia, occasional transverse failures of asbestos-cement pipes occurred...; to overcome these failures, ...research program (was) undertaken... indicating that failure mechanism, responsible for breakage, results from uneven longitudinal bending due to differential swelling of the soil surrounding the pipes; methods of allowing for, or reducing these effects are indicated.

051 PIPING HANDBOOK

R. C. King
McGraw Hill, New York, 5th ed., 1967

Descriptors: Corrosion, Design, Plumbing

Authoritative and accessible data ... in piping design. ... the design of sewerage systems (is) dealt with. Some chapters deal with physical and metallurgical properties of piping material, corrosion, sewerage-systems piping, plumbing systems.

052 NEW TECHNIQUES FOR THE DETECTION OF DEFECTIVE SEWERS

K. W. Brown and D. H. Caldwell
Sewage and Industrial Wastes, Vol. 29, no 9, pp 963-977, 1957

Descriptors: Air Testing, Infiltration, Rainfall

Description of methods used to determine defects in sanitary sewers which are subject to infiltration. Photographic methods and air testing techniques are discussed.

053 LABORATORY INVESTIGATIONS OF SOIL INFILTRATION THROUGH PIPE JOINTS

E. H. Nettles, N. B. Schomaker
National Research Council – Highway Research Board – Research Record, no 203; pp 37-56, 1967

Descriptors: Infiltration, Joints, Permeability, Soils

Investigation of infiltration characteristics of four soils – poorly graded medium to fine sand, uniformly graded fine sand, silt, and lean clay, to develop system of classifying soil according to degree that infiltration through pipe-joint openings may be expected to occur; investigation included design and construction of model simulating prototype pipe joint, study of feasibility of using model for such studies, investigation of variables affecting soil infiltration, and investigation of filtration of soils described.

054 SEWAGE FLOW INVESTIGATIONS AT INVERCARGILL

J. S. Roberts
Proceedings, New Zealand Institution of Engineers, vol 37, pp 286-39, 1950

Descriptors: Flow Measurement, Rainfall, Runoff

A detailed paper on sewage flow measurement correlated with rainfall and infiltration.

055 MILWAUKEE TESTS NEW JOINTS FOR SEWER PIPE

Robert A. Burmeister
APWA Reporter; pp 6-12, December 1962

Descriptors: Joints, Tests

City of Milwaukee has recently completed a series of tests on new joints. Also a new testing procedure was developed and evaluated.

056 ELIMINATION OF STORM WATER FOR SANITARY SEWERS AT WADSWORTH, OHIO

F. G. Randall
Sewage Works Journal, vol 21, no 2; pp 332-333, March 1949

Descriptors: Inflow, Surveillance, Tests

Rubber balls dropped into downspouts to detect whether or not sanitary sewers were misused by leading storm water into them; report on inspection procedure...

057 REDUCTION OF EXCESS SEWAGE FLOWS AT MILWAUKEE

R. D. Leavy
Sewage and Industrial Wastes, vol 26, no 1; pp 34-41, January 1954

Descriptors: Infiltration, Inflow

Storm water finds its way into sanitary sewers by one or more of methods discussed; infiltration, foundation drains, roof downspouts, surface water, cross connections and inadequate drainage basin capacity; methods of reducing excessive flow in intercepting sewers...

058 EQUIPMENT: METHODS, AND RESULTS FOR WASHINGTON, D.C., COMBINED SEWER OVERFLOW STUDIES

C. F. Johnson
Water Pollution Control Federation Journal, vol 33, no 7, pp 721-733, July 1961

Descriptors: Combined Sewers, Overflows, Pollution, Rainfall

Details and comments on combined sewer investigation in Washington, D.C. Rainfall correlation is given.

059 STORM WATER AND COMBINED SEWAGE OVERFLOWS

S. A. Greely, P. E. Langdon
ASCE proc. (Journal of Sanitary Engineering Division), vol 87, NSAI; pt. 1; paper 2718; pp 57-68, January 1961

Descriptors: Combined Sewers, Overflows, Pollution

Aspects of abatement of pollution due to overflows resulting from rainstorms of combined sewer systems of older cities; restriction of overflows by intercepting sewers; treatment of intercepted flow, elimination of combined sewage overflows by construction of new system of sanitary sewers for complete separation.

060 RESIDENTIAL USE AND MISUSE OF SANITARY SEWERS

G. S. Bell
Water Pollution Control Federation Journal, vol 35, no 1; pp 94-99, January 1963

Descriptors: House Connections, Inflow

Discussion of effect of poor house connection construction and illicit connections.

061 "SMOKING OUT" ILLEGAL HOUSE DRAINS

A. Larmon
Wastes Engineering, vol 34, no 11; p 603, November 1963

Descriptors: Inflow, Smoke Tests

Smoke testing equipment consists of portable 1500 c/m Homelite blower, connected by canvas air-duct to sheet of ¾-inch plywood lined with sponge rubber to fit over manhole was used to locate downspouts connected to sanitary sewer system in South Charleston, West Virginia; smoke was applied in manhole by lighting smoke bomb on suction side of blower and discharging it through manhole into sewer.

062 SALT WATER IN THE SEWERS

F. J. Miller
American City, pp 112, 136, December 1965

Descriptors: Salt Water Intrusion

In North Miami, Florida,.salt water was *infiltrating the fresh-water* supply. The solution was in the waste treatment, and not its conveyance.

063 THIS NOT THIS

R. B. Moffitt
Brick and Clay Record, vol 142, no 6, pp 55-57, 76, June 1963

Descriptors: Copper-Ceramic Tile, Copper Sulphate, Roots

Description of experience in retarding root growth in drainage pipe by the use of various forms of metallic and compounds of copper.

064 NEW CAULKING MATERIAL FOR SEWERS

R. m. Starns, Jr.
Western Construction, vol 29, no 5, pp 58-60, 122, May 1954

Descriptors: Caulking, Joints, Leakage

Description of a self-sealing jointing product used on California projects.

065 INVENTORY OF COMBINED SEWER FACILITIES

R. H. Sullivan
Civil Engineering, vol 38; pp 52-53, November 1968

Descriptors: Combined Sewers

A brief description of the 1967 Inventory of Combined Sewer Overflow Facilities conducted by the American Public Works Association for the FWPCA.

066 CONTROLLING ROOTS IN SEWERS BY COPPER SULPHATE

J. W. Wood
AMERICAN PUBLIC WORKS ASSOCIATION, special report no 5, Chicago; 2 pp., 1948

Descriptors: Copper Sulphate, Roots

Discussion of use of Copper Sulphate and its effectiveness.

067 COPPER SULPHATE FOR ROOT AND FUNGUS CONTROL IN SANITARY SEWERS AND STORM DRAINS

J. W. Hood
Phelps Dodge Refining Corp., 40 Wall Street, New York, 21 pp. (illus.), 1949

Descriptors: Copper Sulphate, Roots

Data on damages caused by roots and fungus in sanitary sewers and storm drains such as mechanical obstruction of pipes, odor nuisance, deterioration of structures, reduction in capacity of facilities and sewage treatment difficulties and resultant increase in stream pollution; application of Copper Sulphate and its effects.

068 SEWER CLEANING AND SAFETY MEASURES

N. W. Nester
Water and Sewage Works, vol 105, no 10; pp 420-424, October 1958

Descriptors: Maintenance, Safety, Sewer Cleaning

Causes of sewer stoppages, methods of cleaning sewers...

069 "LAUGHING GAS" SHOWS VALUE IN SPOTTING PIPELINE LEAKS

J. E. Kaufman
Oil and Gas Journal, vol 58, no 8; pp 100-102, February 22, 1960

Descriptors: "Laughing Gas," Nitrous Oxide, Tests

Laboratory tests demonstrate feasibility of nitrous oxide tracer gas in hydrostatic testing of underground lines; as little as 2 ppm of nitrous oxide at surface of ground can be detected by infrared analyzer.

070 HOLLYWOOD LICKED INFILTRATION – BEFORE IT LICKED HOLLYWOOD, (FLORIDA)

J. W. Watson
Wastes Engineering, vol 32, no 8; pp 397-399, August 1961

Descriptors: Grouting, Joints, Leak Detection, Photography, TV Inspection

Description of location of leaks in sewers by photographic method and closed circuit TV and repair by internal chemical sealing and external cement grouting.

071 SEWER LEAKS LOCATED BY SMOKE

J. R. Stallings, Jr.
Civil Engineering, New York, col 32, no 9; p 39, September 1962

Descriptors: Leak Detection, Smoke Tests

Method and procedure for location of major leaks in sewer systems used to solve excessive infiltration problems at Forbes Air Force Base near Topeka, Kansas; smoke tests with portable 1500 cfm Homelite blower with canvas air duct; smoke is applied by isolating section of sewer by sandbagging in sewer manholes.

072 CHEMICAL SEAL STOPS SEWER INFILTRATION

F. D. Dahlmeyer
Public Works, vol 93, no 11; pp 91-92

Descriptors: Joints, Sealant

Treatment process to stabilize and waterproof soil surrounding sewer line by introduction of chemical grout which, after exposure to catalyst solution forms stiff gel that is impermeable to water; tests before and after treatment proved advantages of method which avoids problems of open excavations.

073 A FOUR-WAY PROGRAM OF SEWER REHABILITATION

E. J. Baugh
American City, p 117, March 1964

Descriptors: Maintenance, Tests, TV Inspection

1) Cleaning all sewers on a year-round basis; 2) TV inspection; 3) dye-testing from downspouts and sanitary connections to pinpoint illegal sanitary and storm connections; 4) repair or replacement of faulty sewers.

074 KNOW WHEN TO HOLLER FOR HELP

R. Brubacher
American City, pp 92-93, May 1964

Descriptors: TV Inspection

TV inspection in sewer spots infiltration

075 A SEARCH TO SOLVE THE SINKING SEWER PROBLEM

American City, p 38, May 1965

Descriptors: Sewer Stability

Through field and laboratory tests... an answer to the sinking sewer problem in the Gulf Coast Region... and... a... study of infiltration will be attempted.

076 NO NEED FOR EMERGENCIES IN THIS STEPPED-UP SEWER-CLEANING AND MAINTENANCE PROGRAM

J. M. Dick
American City, vol 79, no 5, pp 103-104, May 1964

Descriptors: Maintenance, Roots

Solution of stoppage problems in Dearborn, Michigan sewer system where lack of rain and continuing drop of water table caused tree roots to seek moisture from sewers;... continuous rodders keep 4 sets of bucket machines with truck loaders in operation and average approximately additional 1500 ft./day root-cutting.

077 SEAL SEWER LEAKS FROM THE INSIDE

R. Nooe
American City, pp 91-92, June 1964

Descriptors: Sealing, TV Inspection

Repairing sewers without digging will save Fort Myers, Florida, around $2,000,000. in the next 20 years. Television inspection and internal sealing of leaks.

078 LOOK RIGHT INTO YOUR SEWER PROBLEMS

J. A. Kern
American City, pp 81-85, August 1964

Descriptors: TV Inspection

Closed-circuit television in Manheim Township, Pennsylvania (revealing infiltration and inflow.)

079 ISOLATING THE CAUSES OF INFILTRATION

A. T. Brokaw
American City, p 80, December 1964

Descriptors: Illicit Connections, Inflow, Photography

Princeton, New Jersey,... is... stopping complaints about flooded basements and other irritations with sewer photography, house inspection and other controls...

080 SEWERS CAN BE REBUILT BY REMOTE CONTROL

G. Rutz
Water Works and Wastes Engineering vol 2, no 10; p 42, 1965

Descriptors: Repairs, TV Inspection

Locating points of infiltration with closed circuit (TV) before repair operations.

081 CATCHING UP ON DEFERRED MAINTENANCE AT KANSAS CITY, MISSOURI

G. T. Hopkins, O. C. Hopkins, F. L. Kramer
Water Pollution Control Federation, vol 37, no 2; p 236, February 1965

Descriptors: Maintenance, TV Inspection

Description of program of maintenance and testing for illicit connections and repairs.

082 TV PLUS GROUT

American City, pp 112-113, April 1965

Descriptors: Grouting, Repairs, TV Inspection

Indianapolis' leaking sewer system was detected with TV and corrected with grout.

083 GROUTING TECHNIQUE CUTS SEWER REPAIR COSTS

R. H. Batterman
Public Works, pp 102-103, May 1965

Descriptors: Grouting, TV Inspection

Grouting machine follows TV camera in sewer.

084 SOIL FUMIGANTS CONTROL ROOTS IN SEWERS

G. Z. Rayner
American City, pp 135-136, June 1965

Descriptors: Roots

Milwaukee has developed a way to make sewers root-free for at least two years, using a chemical foam.

085 AN UNUSUAL PHOTOGRAPHIC PIPELINE SURVEY

G. P. Fulton
Public Works, pp 85-87, July 1965

Descriptors: Inspection, Photography

Walk-through inspection was ruled out; survey equipment included camera and strobe flashlight mounted on float connected by cable to two counterweighted canisters holding additional strobe lights... lowered into downstream end of sewer reach and attached to coaxial cable running to next upstream manhole; pictures were taken at 5 foot intervals.

086 SEWER INSPECTION AND MAINTENANCE

J. R. Finn
Public Works, p 150, October 1965

Descriptors: Inspection, Maintenance

Common ills with sewers, methods of inspection, and protective measures.

087 THE MODERN WAY TO INSPECT AND REPAIR SEWERS

T. W. Clapham
Public Works, pp 90-92, December 1965

Descriptors: Inspection, Repairs

Grouting and TV technique in Little Rock Arkansas

088 TV PROVES USEFUL FOR SEWER INSPECTION

R. H. Hayes
Civil Engineering, vol 36; pp 66-68, January 1966

Descriptors: TV Inspection

Description of examples of TV inspection techniques in sewers.

089 PHOTOGRAPHIC SEWER INSPECTIONS REQUIRED BY ORDINANCE

R. E. Falardeau
Public Works, pp 93-95, March 1966

Descriptors: Inspection, Photography

Result: a film library of the entire sewer system, and improved maintenance.

090 SEATTLE'S TV SEWER INSPECTION SYSTEM

H. T. Thornquist
Water and Sewage Works, vol 113, no 3; pp 82-83

Descriptors: TV Inspection

Winch truck provides mechanical means of pulling camera through sewer...

091 SEWER INSPECTION PHOTOGRAPHS CAN RESOLVE CONTROVERSIES

R. E. Falardeau
Public Works, p 118, December 1966

Descriptors: Inspection, Photography

Problems and procedures in interpreting the photographs; a concensus of professional engineers is best.

092 EVALUATION OF EXTERNAL SEALING METHOD TO REDUCE STORM FLOW EFFECTS IN SEWERAGE SYSTEMS,

Final Progress Report
FWPCA Demonstration Grant WPD 111-01-66, County of Sonoma, California, Sanitation Department
Project Director – Donald B. Head, Sanitary Engineer

Descriptors: Asphalt Compounds, Joints, Sealing

Test of new methods of external sealing with asphaltic compounds. Equipment developed and correlation between infiltration and exfiltration pursued. Correlation with rainfall also developed.

093 CONTROL OF SEWER ROOT PROBLEMS WITH COPPER SULPHATE

R. Marshall
Public Works; pp 110-112, April 1967

Descriptors: Copper Sulphate, Roots

Engineering approach to the problem, plus considerations and methods of dealing with the public when, for example, a municipal worker had to enter a home, as the job required.

094 SEALING PROCESS RESOLVES INFILTRATION PROBLEM

S. G. Stepp
Public Works; pp 70-73, July 1967

Descriptors: Joints, Sealing

At St. Augustine, infiltration problems were compounded by the closely built old buildings in some sections of the city. Listed are all the approaches considered, the description of the job and the results.

095 INVENTION PROTECTS HOMES FROM BACKWATER DAMAGE

W. C. Dalton
Public Works; pp 137-139. October 1967

Descriptors: Backwater Protection

Wherever lowest waste drainage connection of building is below point of relief on colector sewer, danger of backwater damage exists unless precautions are provided; developed emergency backwater overflow device is self-sealing ball float valve with nose cone deflector; sectional view of original device, and one of new design.

096 TV INSPECTION AND IN-PLACE GROUTING OF SEWERS

R. H. White
Water and Wastes Engineering, vol 5, no 9; p 72, 1968

Descriptors: Grouting, Joints, TV Inspection

Austin, Texas, used TV camera inspection to identify and locate broken pipe sections.... Austin utilized in-place grouting and sewer repairs to reduce infiltration and develop a program which reviewed 209,597 feet during 1966 to 1967.

097 SCOURED SEWERS AND TV INSPECTION

American City; p 118, February 1968

Descriptors: Maintenance, TV Inspection

Water jet cleaner flushes and scours pipe at 1000 ft. per hour. Under normal use, it requires one gallon of water per foot of pipe cleaned. ...in locating sources of trouble such as cracked pipe, tree roots, incorrect service taps, and lost service lines (a closed circuit TV had been used.) A custom-built trailer houses the entire TV system and provides... viewing... during operations.

098 REMOTE CONTROL GROUTING OF SEWER LINE LEAKS

J. Metz
Water and Wastes Engineering, vol 5, no 6; p 68, 1968

Descriptors: Grouting

The Merriville Conservancy District used remote control grouting... grouting packer was used to pump grout into... leak.

099 MASSIVE SEWER INFILTRATION

T. E. Llewellyn
American City, vol 83, no 10; p 90, 1968

Descriptors: Investigations, Joints, Sealant

North Tahoe public utility districts (have) suffered from surcharged sewers, manholes, and overloaded pump stations. The district began a program to combat excessive infiltration. An investigative phase was followed by corrective action. Key West, Florida, uses a sealant to control infiltration... introduced into a sewer between adjacent plugged manholes.

100 BARGAIN REPAIRS WITH TV AND GROUT

D. Hurlbert
Public Works; pp 106-107, September 1968

Descriptors: Grouting, Joints, TV Inspection

Description of planning, inspection and grouting of leaking sewer joints in Kansas City, Missouri.

101 ELIMINATING SEWER LEAKS – FROM THE INSIDE AND OUTSIDE

C. P. Aguero
American City, October 1968

Descriptors: Economics, Grouting, Joints, Sealant

In two weeks, city crew eliminated ½ mgd. of infiltration. Methods and costs are described.

102 WHAT JET SEWER CLEANERS DO TO SEWER JOINTS

I. W. Santry, Jr.
American City, vol 83, no 11; pp 96-97, November 1968

Descriptors: Jet Cleaners, Joints, Maintenance

Tests conducted at Garland, Texas, Water Utilities Department, to find out what strong jet action of new machines using high pressure hydraulic jets does to sewer joints as it passes through line; results showed that there was no damage from jet spray if line was properly constructed.

103 REPORT ON PLASTIC LINING OF OLD SEWER PIPES IN TORONTO, ONTARIO

R. M. Bremner
Report to City Council, May 21, 1969

Descriptors: Economics, Liners

Report outlining method and costs of placing plastic liner in existing leaking sewers.

104 SEWERS FOR GROWING AMERICA

Dr. M. M. Cohn
Certainteed Products Corporation; 1966

Descriptors: Construction, Design, Economics, Planning

Authoritative manual on history and development of sewer systems in America. Contains sections on planning, design, financing and construction of sewers.

105 THE DETECTION AND SEALING OF LEAKS IN SEWERS

B. W. Brunton
Canadian Municipal Utilities, vol 101, no 12, pp 22-23, December 1963

Descriptors: Economics of Correction, Grouting, Sealant, TV Inspection

Discussion of dangers and costs of infiltration in Sudbury, Ontario. Also reviews the Penetryn system of TV inspection and grouting. Costs are given.

106 CUSTOM BUILT SEWER TV

Canadian Municipal Utilities, vol 103, no 2, pp 32-33, February 1964

Descriptors: TV Inspection

Scarborough, Ontario has purchased its own custom TV inspection equipment rather than rental equipment. Costs are given.

107 THE DEGRADATION OF NATURAL RUBBER PIPE JOINT RINGS

D. A. Hills
Rubber Journal, vol 149, no 11, pp 12-13, 15, 17, 77 November 1967

Descriptors: Joints, Rubber Rings

Deterioration of rubber pipe joints due to bacterial action. Research report.

108 OVERLAND FLOW AND GROUNDWATER FLOW FROM A STEADY RAINFALL OF FINITE DURATION

F. M. Henderson, R. A. Wooding
Journal of Geophysical Research, vol. 69, no 8, pp 1531-1540, April 15, 1964

Descriptors: Design, Groundwater, Rainfall, Runoff

Development of mathematical analysis of rainfall effects on ground and surface water drainage.

109 OVERLOADING OF SEWERS: SOME CORRECTIVE MEASURES AND CONTEMPLATED IMPROVEMENTS

W. H. Bolton
Seventy-Fourth Annual Report, Connecticut Society of Civil Engineers, pp 35-41, 1958

Descriptors: Combined Sewers, Joints, Repairs, Sanitary Sewers, Storm Sewers

Review of experience in New Haven, Connecticut with failures of storm and sanitary sewers due to floods, infiltration and other overload conditions.

110 DEFECTIVE SEWER RELINING WITHOUT EXCAVATION

The Surveyor, vol 123, no 3745, p 42, 1964

Descriptors: Gunite, Relining, Sewer Repair

Brief explanation of gunite and other techniques developed by William F. Rees, Ltd., to repair and seal old sewers in place. Work was performed in London, England.

111 TRACING INFILTRATION IN SEWERS

J. Gaskin
The Surveyor, vol 109, no 3064, p 605, November 24, 1950

Descriptors: Infiltration

Description of early methods to locate infiltration in England.

112 HANDBOOK OF DRAINAGE AND CONSTRUCTION PRODUCTS

Armco Drainage and Metal Products, Inc.
Middletown, Ohio

Descriptors: Design, Drainage, Steel Pipe

Valuable design and construction information for storm and sanitary sewers. Many tables, graphs, charts and references.

113 CONCRETE PIPE HANDBOOK

American Concrete Pipe Association
Arlington, Virginia

Descriptors: Design, Concrete Pipe

Authoritative information on design and construction standards for concrete pipe.

114 REGULATIONS OF SEWER USE

Water Pollution Control Federation Manual No. 3
Washington, D.C.

Descriptors: Regulations

A review of regulatory ordinances and methods for controlling sewer use.

115 SEWER MAINTENANCE

Water Pollution Control Federation, Manual No. 7
Washington, D.C.

Descriptors: Maintenance

Authoritative manual of recommended practice in the field of sewer maintenance.

116 REHABILITATION OF A CONCRETE SEWER UNDER INFILTRATION PRESSURE

Harold H. Haugh
Public Works, vol 100, no 7, pp 89-90, July 1969

Descriptors: Concrete Pipe, Grouting

Description of repairs to concrete pipe sewer with a special gunite process.

117 SEWERS NEED BETTER SOILS ENGINEERING

Joseph S. Ward
American City, vol 84, no 7, pp 72-74

Descriptors: Construction, Design, Soils

Discussion of the role of the soils engineer in sewer design and to insure better construction, to save money and to simplify the work.

118 HANDBOOK OF CAST IRON PIPE

Cast Iron Pipe Association
Oak Brook, Illinois

Descriptors: Cast Iron Pipe

Design handbook for sewer and water systems with cast iron pipe.

119 DALLAS HAS MODERN APPROACH TO SEWER INSTALLATION

H. J. Graeser
Water and Sewage Works, vol 226, no 9, pp 326-331, September 1969

Descriptors: Construction, Joints

A discussion of current materials, pipes, joints and methods utilized to produce tight sewer system. An analysis of future needs for development.

120 A PLASTIC SEWER LINER

R. M. Bremner
American City, vol. 84, no 9, pp 98-101, September 1969

Descriptors: Liners

The rehabilitation of small-diameter sewers at two-thirds of the cost and one-third of the time required for reconstruction.

121 LOW PRESSURE AIR TESTS FOR SEWER LINES

W. J. Malcolm
American City, vol 84, no 11, pp 74-75, November 1969

Descriptors: Air-testing

A series of questions and answers on the subject of low-pressure air testing.

122 WE KEPT THE SEWER IN SERVICE

Jack D. Foster and Jack W. Tooley
American City, vol 84, no 11, pp 97-99, November 1969

Descriptors: Liners

Description of use of a new reinforced plastic mortar pipe, Techite, in a seriously corroded interceptor in Oakland, California.

123 ABS TRUSS PIPE FOR SEWERS

T. L. Willhoff
Water and Wastes Engineering, vol 6, no 3, pp 40,42, March 1969

Descriptors: Plastic Pipe, Truss Pipe

Description of ABS truss pipe which has been developed for sewers. Results of tests are given.

124 SEWER PIPE SETTLEMENT STUDIES

Civil Engineering – ASCE, p 70, October 1965

Descriptors: Soils

125 EXFILTRATION TESTING OF LARGE SEWERS IN KANSAS CITY, MISSOURI

Jerome F. Fladring and Lloyd W. Weller
Water and Wastes Engineering, pp 87-89, September 1967

Descriptors: Exfiltration, Tests

Description of methods for testing sewers in Kansas City.

126 INFILTRATION IN SANITARY SEWERS

I. W. Santry, Jr.
Water Pollution Control Federation, Journal, pp 1256-1261, October 1964

Descriptors: Infiltration

General discussion of infiltration problem in sanitary sewers.

127 PRACTICAL METHODS FOR DETERMINING SEWAGE FLOW FOR ALL COMMUNITIES

R. M. Girling
Water and Sewage Works, pp 250-258, July 1969

Descriptors: Flow Measurements

Review of methods used for measuring sewage flow.

128 MODERN SEWAGE TREATMENT PLANTS – HOW MUCH DO THEY COST?

U. S. Public Health Service
Division of Water Supply and Pollution Control, 1964

Descriptors: Economics

...guidelines derived from the PHS data reflects the varying costs of sewage treatment plant construction as influenced by size of plant, type of treatment, ...and other factors. The answers provide a dependable base for future financing practices....

129 ESTIMATING SEWAGE TREATMENT PLANT OPERATION AND MAINTENANCE COSTS

P. P. Rowan, K. L. Jenkins, D. H. Howells
Journal of the Water Pollution Control Federation, vol 33; February, 1961

Descriptors: Economics

The report is based on a PHS survey of municipal treatment plants throughout the United States. The data are summarized by type of treatment and size of plant of primary and secondary treatment systems.

130 THE ECONOMICS OF URBAN SEWAGE DISPOSAL

Paul B. Downing
Frederick A. Praeger, Publishers, New York, 1969

Descriptors: Economics

The report examines the various costs of collection and treatment, optional system sizes, water quality standards and the financing of urban sewage facilities.

131 LOW PRESSURE AIR TESTING OF SEWERS

William J. Chase, Harvey W.
Pacific Northwest Pollution Control Association Meeting, Vancouver, Washington November 5, 1965

Descriptors: Air Testing

The report includes review of the test development, discussions of experiences, recommended specifications, and equipment sketches.

132 PLASTIC LINER REPAIRS LEAKING SEWER

Lyle D. Johnson
Public Works, June 1970, pp 85-86

Descriptors: Repairs

A 54 in. outfall was sealed by using a 26 oz per sq yd PVC sheet sandwich reinforced with Polyester fabric.

133 BOCA BASIC PLUMBING CODE, 1970

Building Officials and Code Administrators International, Inc., Chicago, Illinois

Descriptors: Plumbing

A model code

134 SOUTHERN STANDARD PLUMBING CODE, 1967

Southern Building Code Congress, Birmingham, Alabama

Descriptors: Plumbing

A model code

135 UNIFORM PLUMBING CODE

International Association of Plumbing and Mechanical Officials, Los Angeles, California

Descriptors: Plumbing

A model code

1 *Accession Number*

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2 *Subject Field & Group*

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 *Organization*

The American Public Works Association, Chicago, Illinois 60637

6 *Title*

CONTROL OF INFILTRATION AND INFLOW INTO SEWER SYSTEMS

10 *Author(s)*

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22 *Citation*

23 *Descriptors (Starred First)*

Infiltration,* Inflow,* Investigations,* Inspection, Survey

25 *Identifiers (Starred First)*

Construction allowance

27 *Abstract*

ABSTRACT

Two hundred and twelve public jurisdictions in the United States and Canada were contacted, and twenty-six communities were visited. Practices of consulting engineers and state and provincial water pollution control agencies were also surveyed.

The surveys indicated that infiltration and inflow are widespread problems.

Reduction of infiltration should be stressed in both new and old systems. For new sewers a construction allowance of no more than 200 gallons per day per inch of diameter per mile of pipe is recommended. Existing systems must be extensively investigated to determine the extent and location of infiltration. Reduction of inflow waters can be accomplished after sources of such flows have been identified, alternate methods of disposal identified, and the backing of public and governing bodies secured.

Twenty recommendations are given indicating the need for extensive investigation of the extent of the infiltration/inflow problem before relief sewers are constructed or wastewater treatment plants built or enlarged.

The report includes 43 tables, an extensive review of reports concerning local infiltration studies, and a bibliography of 135 references.

This report was prepared for the Environmental Protection Agency in fulfillment of Contract 14-12-550. The study was also supported by thirty-nine public agencies. A companion document, "Manual of Practice, Prevention and Correction of Excessive Infiltration and Inflow into Sewer Systems," was also prepared.

Abstractor Richard H. Sullivan

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11020 --- 12/67	Problems of Combined Sewer Facilities and Overflows, 1967, (WP-20-11)
11023 --- 05/68	Feasibility of a Stabilization-Retention Basin in Lake Erie at Cleveland, Ohio
11031 --- 08/68	The Beneficial Use of Storm Water
11030 DNS 01/69	Water Pollution Aspects of Urban Runoff, (WP-20-15)
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11020 DES 06/69	Selected Urban Storm Water Runoff Abstracts, (WP-20-21)
11020 --- 06/69	Sewer Infiltration Reduction by Zone Pumping, (DAST-9)
11020 EXV 07/69	Strainer/Filter Treatment of Combined Sewer Overflows, (WP-20-16)
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11023 FDD 03/70	Rotary Vibratory Fine Screening of Combined Sewer Overflows, (DAST-5)
11024 DMS 05/70	Engineering Investigation of Sewer Overflow Problem - Roanoke, Virginia
11023 EVO 06/70	Microstraining and Disinfection of Combined Sewer Overflows
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